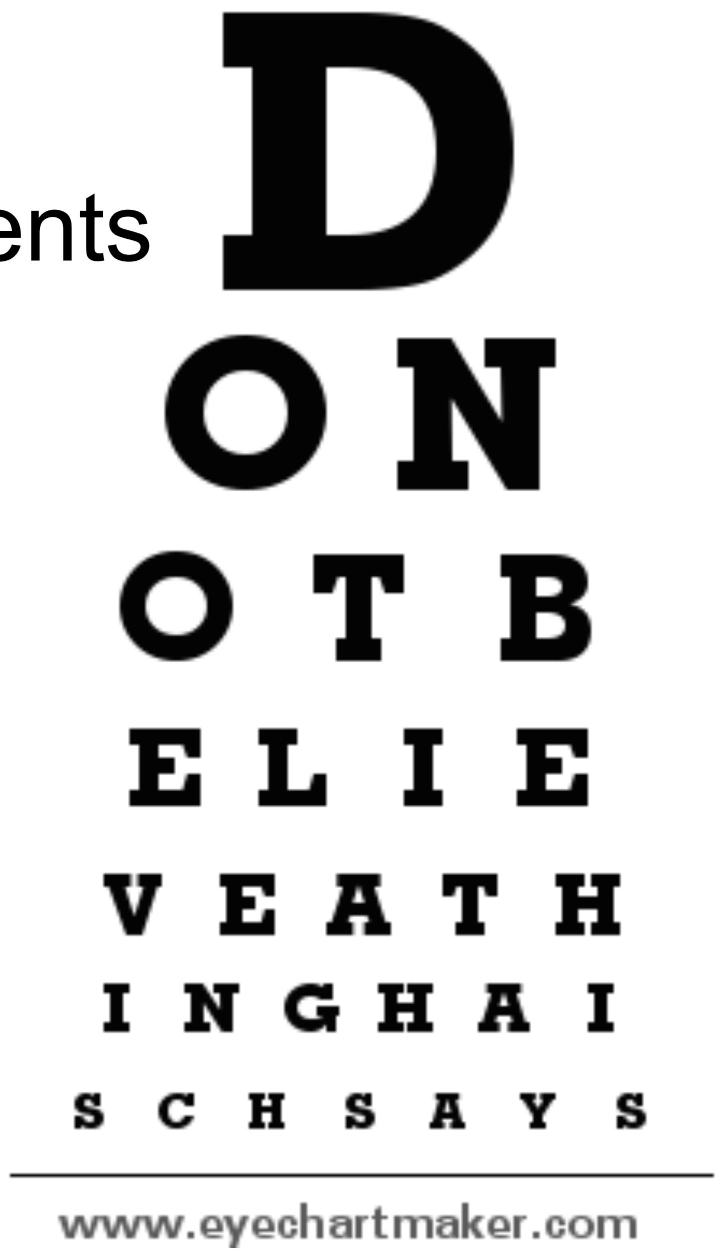
Top-quark measurements at LHCb

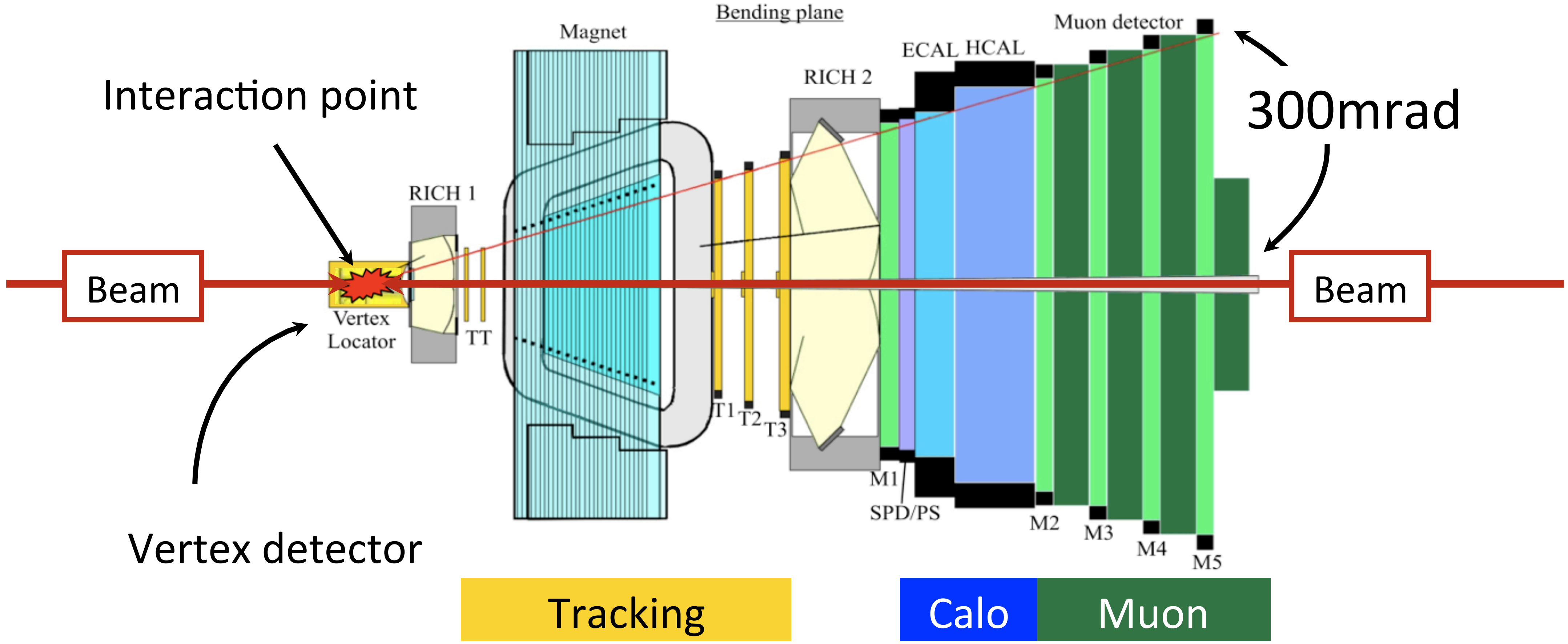
Rhorry Gauld

Contents

- Introduction and motivations
- Feasibility of cross section measurements
    - arXiv 1311.1810
- Charge asymmetry measurements
    - coming soon



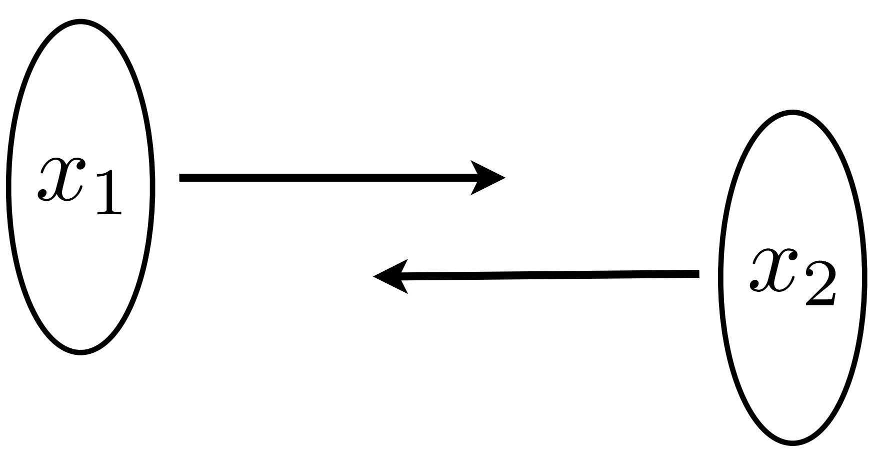
LHCb - important details



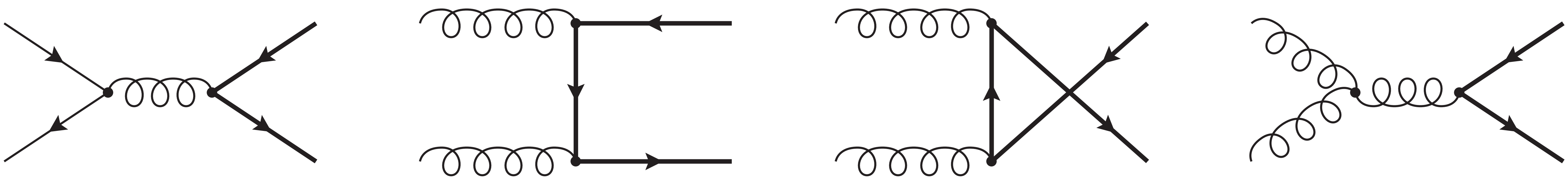
- LHCb: a general purpose detector instrumented within $2 \leq \eta \leq 5$
  Recorded/Potential luminosity:
  - (2011): 1.1 fb^{-1} $\sqrt{s} = 7$ TeV
  - (2012): 2.1 fb^{-1} $\sqrt{s} = 8$ TeV
  - (2015-2017): ~5 fb^{-1} $\sqrt{s} = 13$ TeV
  - (2020-2030): ~50 fb^{-1} $\sqrt{s} = 14$ TeV

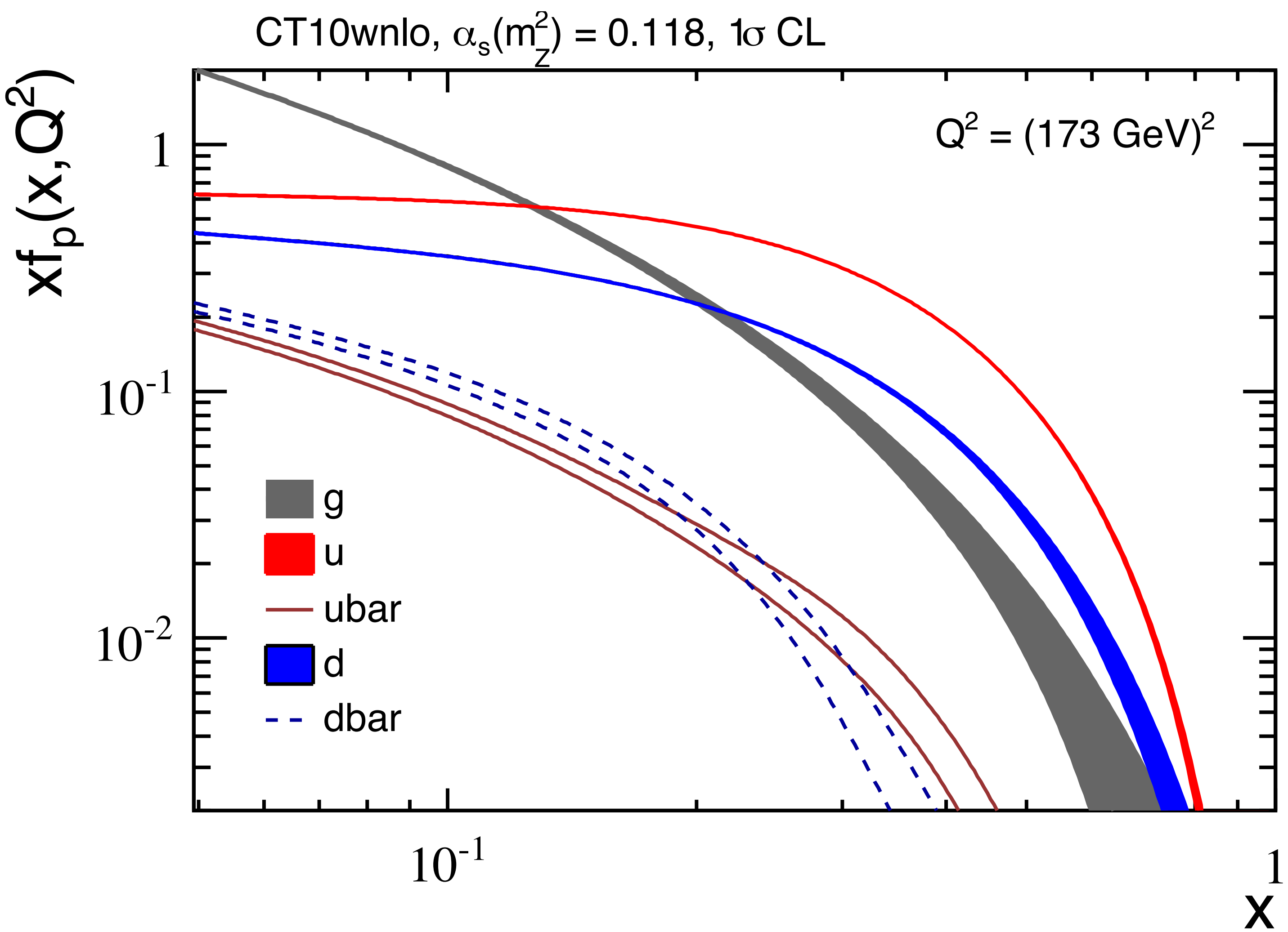
Why study forward ttbar?

$$x_{1,(2)} = \frac{m_T}{\sqrt{\hat{s}}}\left(e^{(-)y_3} + e^{(-)y_4}\right)$$

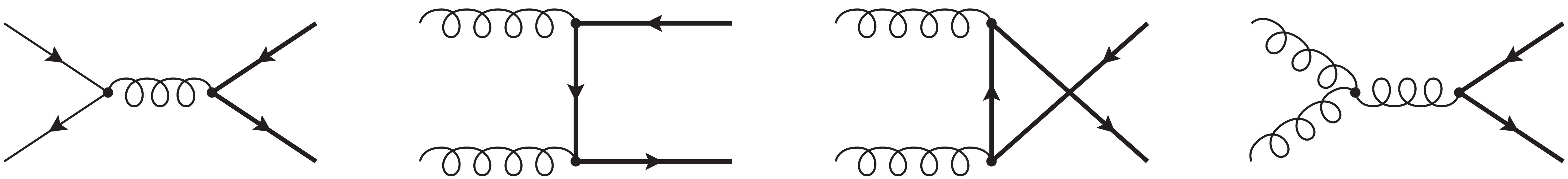


Why study forward ttbar?

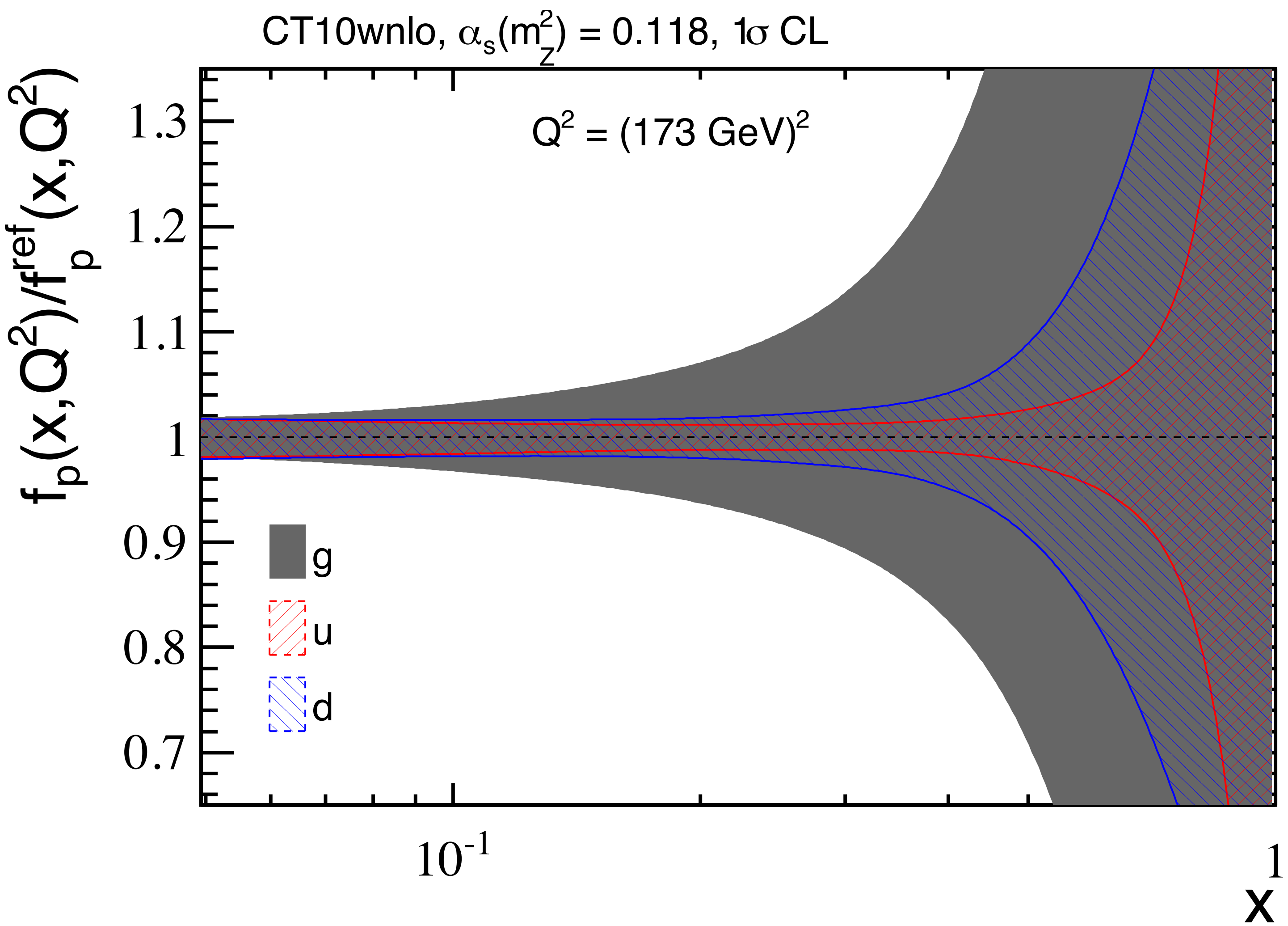




Why study forward ttbar?

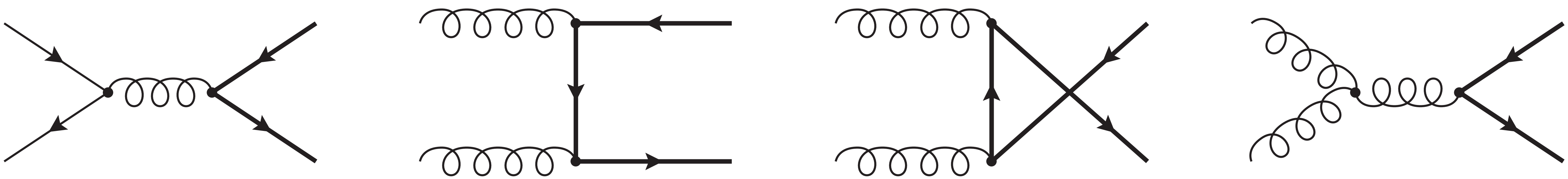


1) PDF constraints

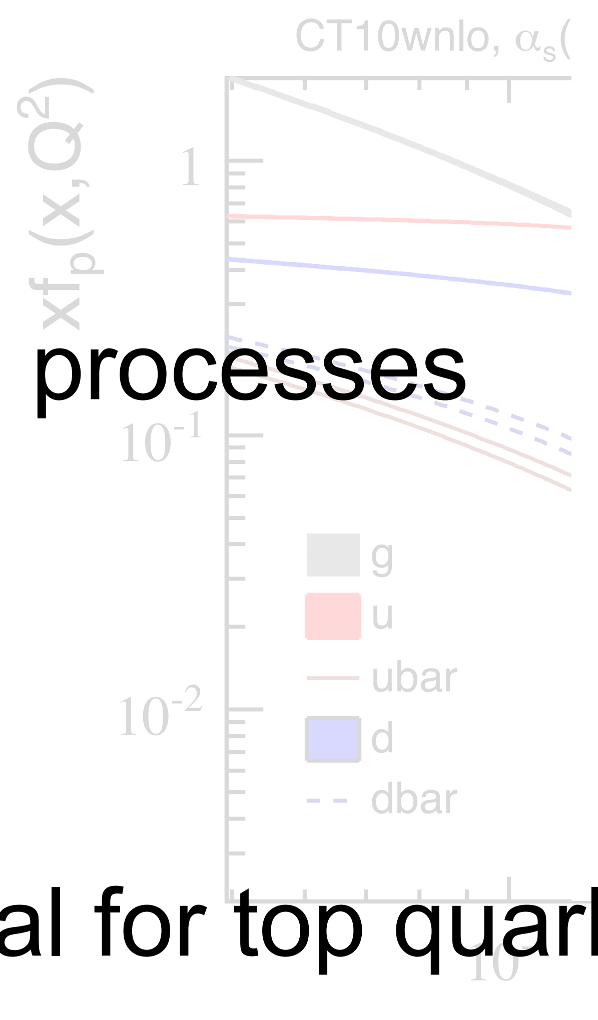


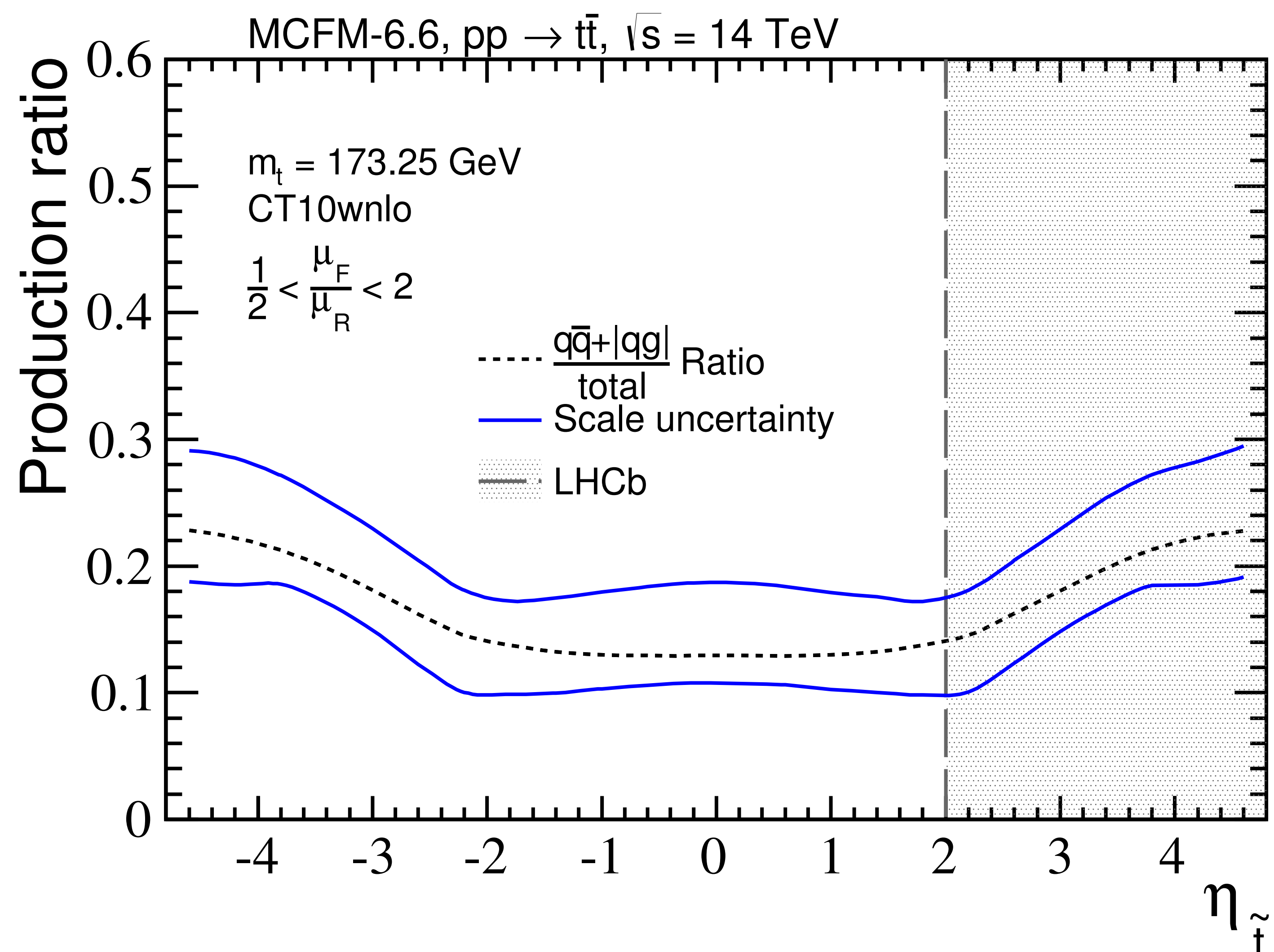
relative PDF uncertainty (1sigma)

Why study forward ttbar?



2) q-initiated processes





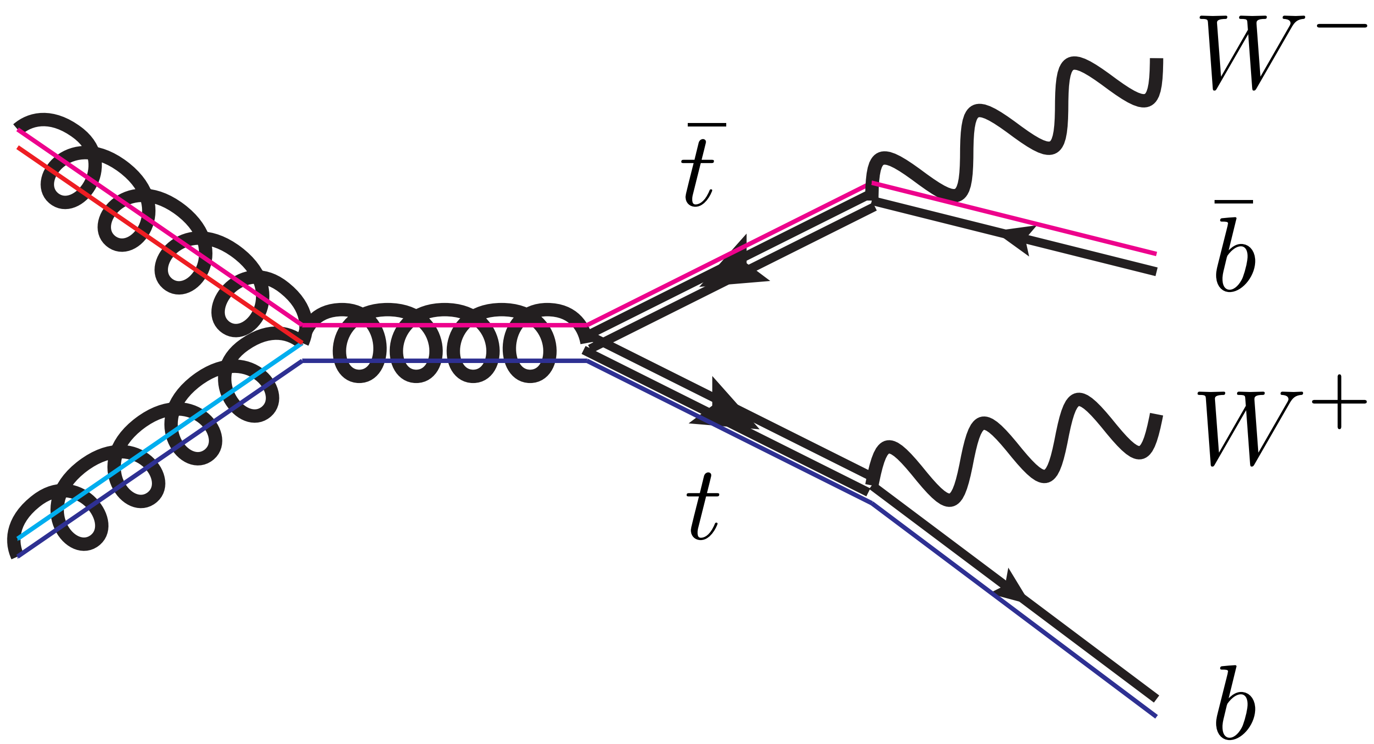
|qx|/total for top quark pseudorapidity distribution

cross section measurements

Final state selection

Top studies at LHCb proposed here,
arXiv:1103.3747 A. Kagan, J. Kamenik, G. Perez, S. Stone
arXiv:1311.1810 RG (this work)

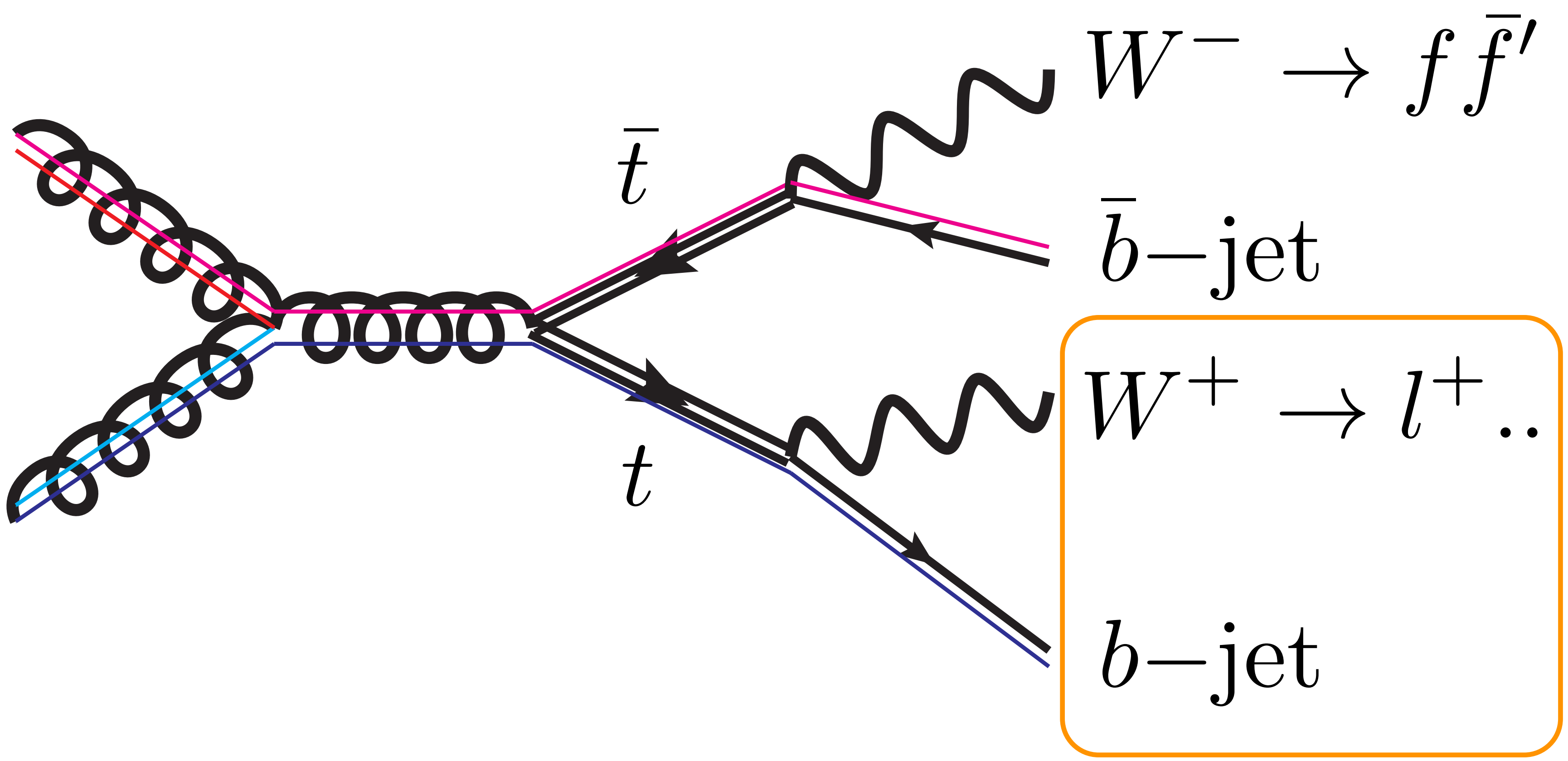
Have to select realistic final states



Final state selection

Top studies at LHCb proposed here,
arXiv:1103.3747 A. Kagan, J. Kamenik, G. Perez, S. Stone
arXiv:1311.1810 RG (this work)

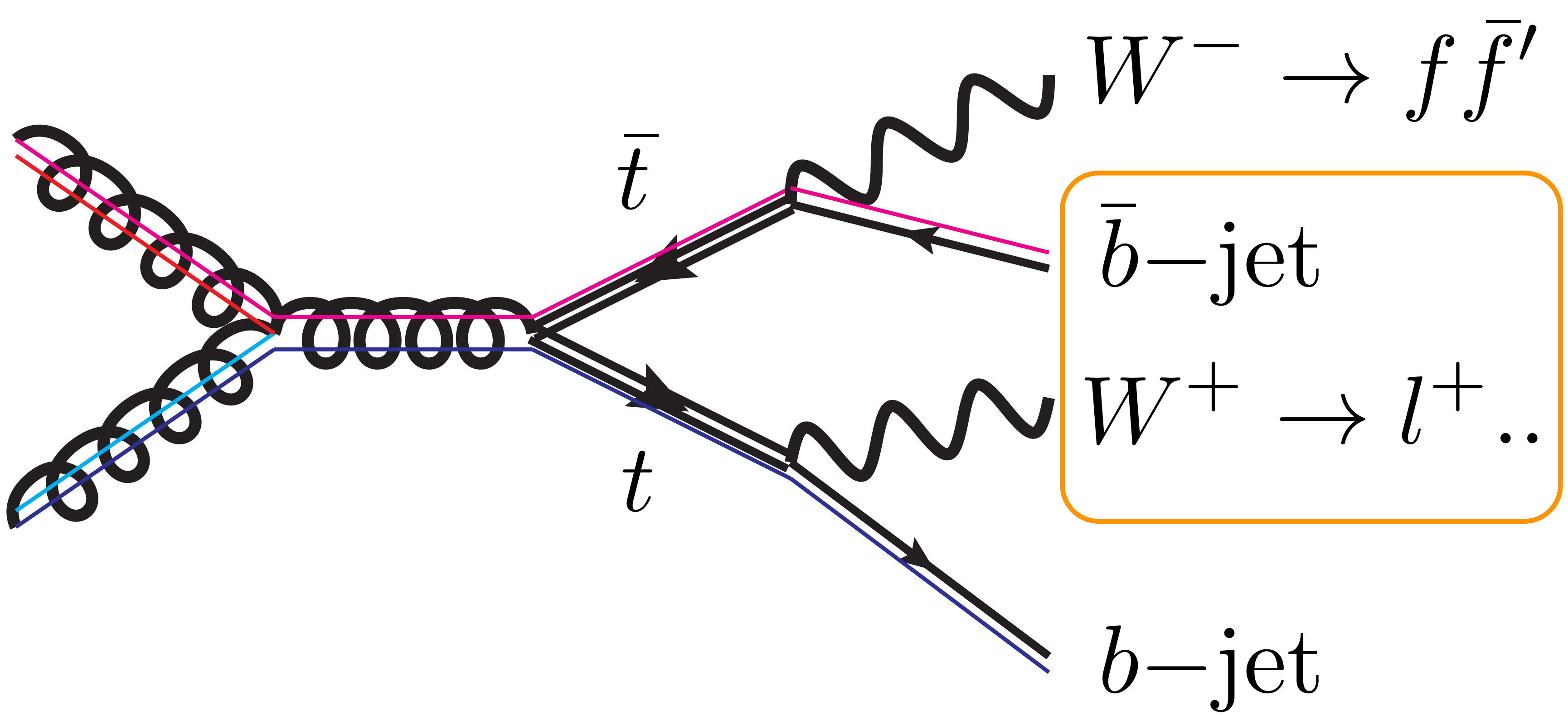
Have to select realistic final states



Final state selection

Top studies at LHCb proposed here,
arXiv:1103.3747 A. Kagan, J. Kamenik, G. Perez, S. Stone
arXiv:1311.1810 RG (this work)

Have to select realistic final states



Final state selection

Top studies at LHCb proposed here,
arXiv:1103.3747 A. Kagan, J. Kamenik, G. Perez, S. Stone
arXiv:1311.1810 RG (this work)

single-lepton $t\bar{t} \to l^{\mp} b X$

di-lepton $t\bar{t} \to e^{\pm} \mu^{\mp} b X$

Single-lepton

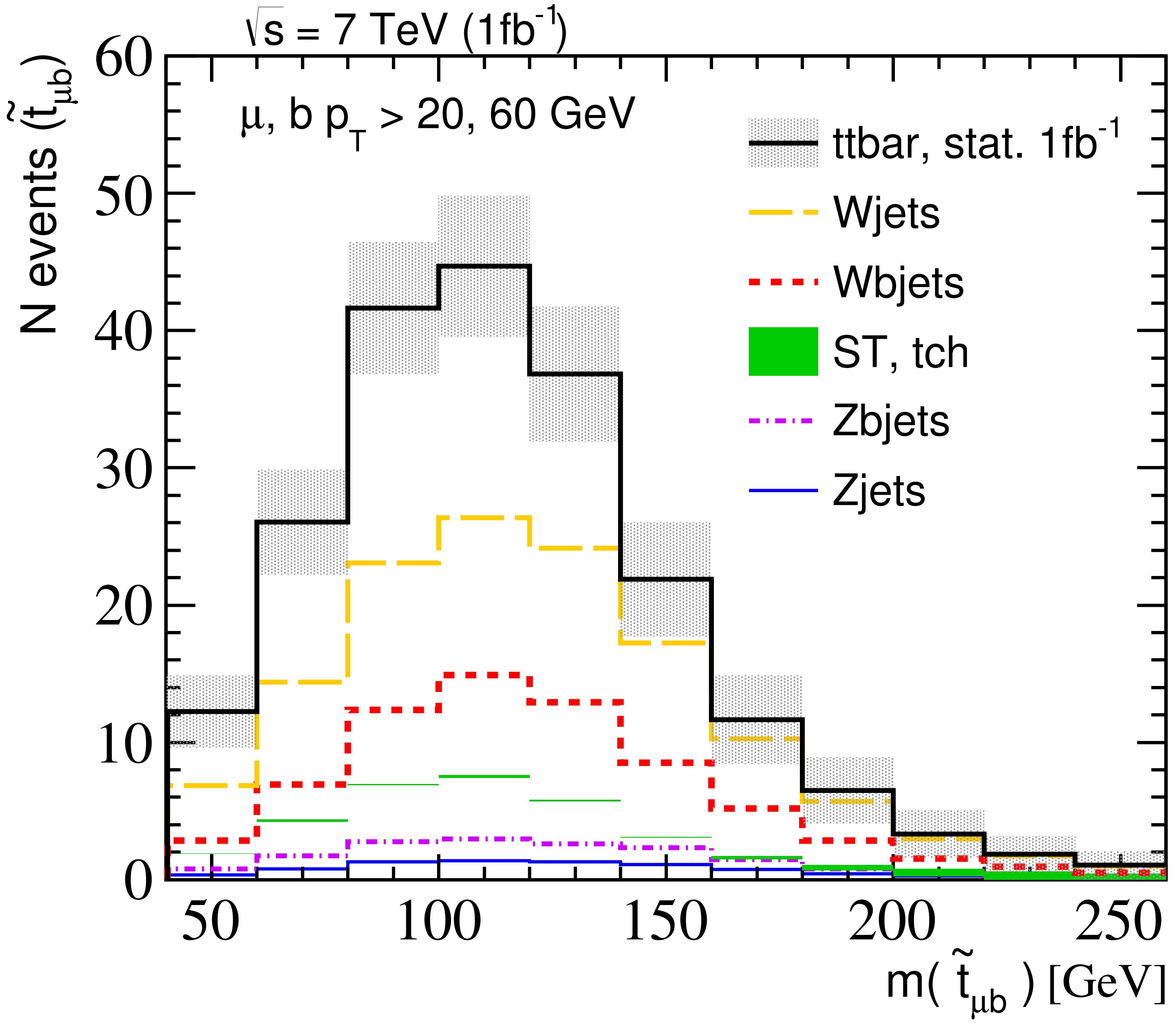
- generate samples (**POWHEG**) and match to parton shower (**Pythia8176**)
- apply <u>realistic</u> cuts: **l pT > 20 GeV** and **b pT > 60 GeV**
- apply b-tagging efficiencies: 70% efficiency and 1% mis-tag (non b-jet)
- apply muon efficiencies: 75% (trigger, identification, reconstruction)
- apply muon isolation: dR (mu, j/b) > 0.5

$$7\ TeV$$

$$l^{\pm}b$$

N events expected

2011 - 1 ifb



Single-lepton

- generate samples (**POWHEG**) and match to parton shower (**Pythia8176**)
- apply <u>realistic</u> cuts: **l pT > 20 GeV** and **b pT > 60 GeV**
- apply b-tagging efficiencies: 70% efficiency and 1% mis-tag (non b-jet)
- apply muon efficiencies: 75% (trigger, identification, reconstruction)
- apply muon isolation: dR (mu, j/b) > 0.5

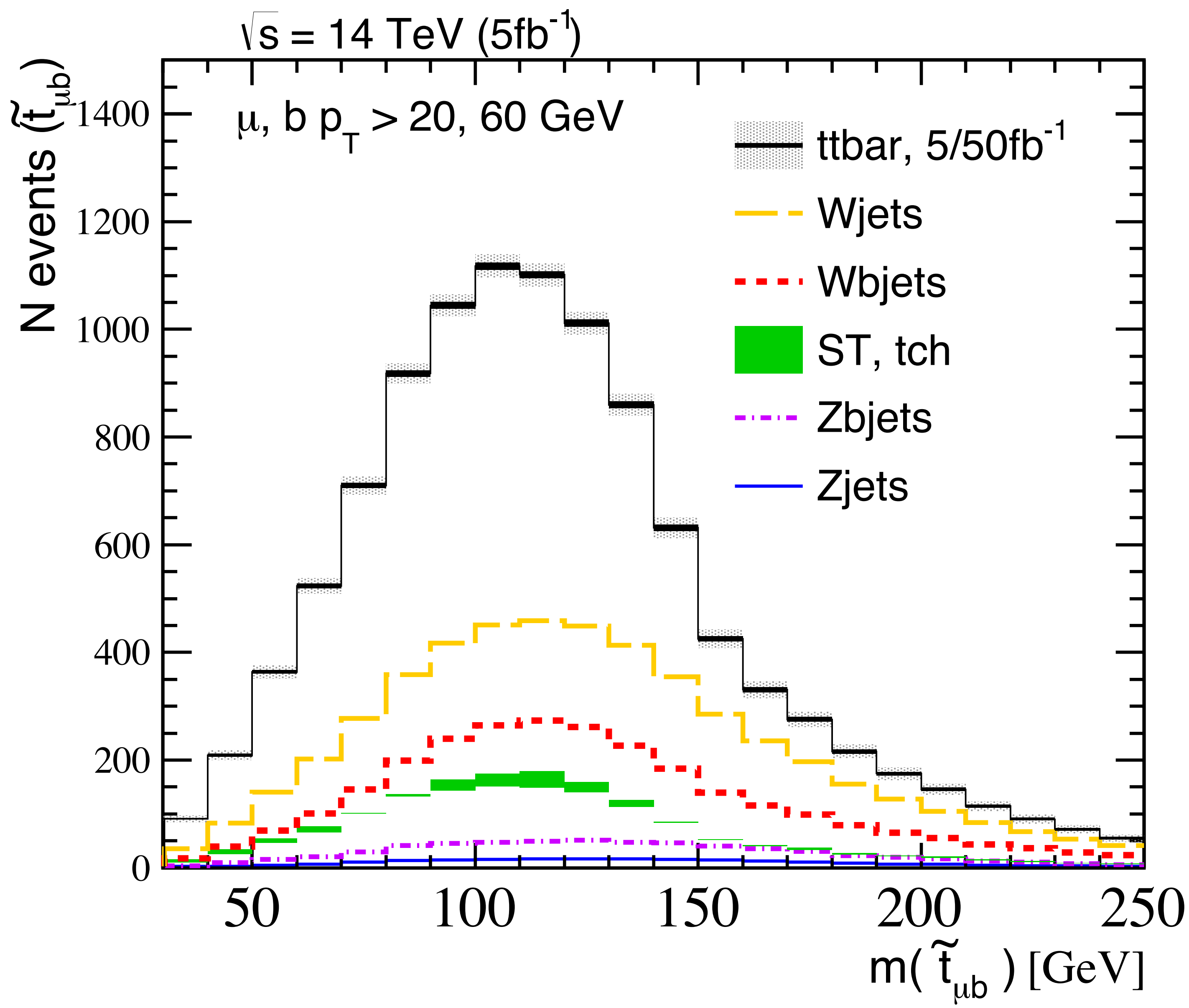
$$14\ TeV$$

$$l^{\pm}b$$

N events expected

2017 - 5 ifb

2030 - 50 ifb



Di-lepton

- generate samples (**POWHEG**) and match to parton shower (**Pythia8176**)
- apply <u>realistic</u> cuts: **mu/e/b pT > 20 GeV**
- apply b-tagging efficiencies: 90% efficiency and 5% mis-tag (non b-jet)
- apply muon efficiencies: 75% (trigger, identification, reconstruction)
- apply muon isolation: dR (mu, j/b) > 0.5

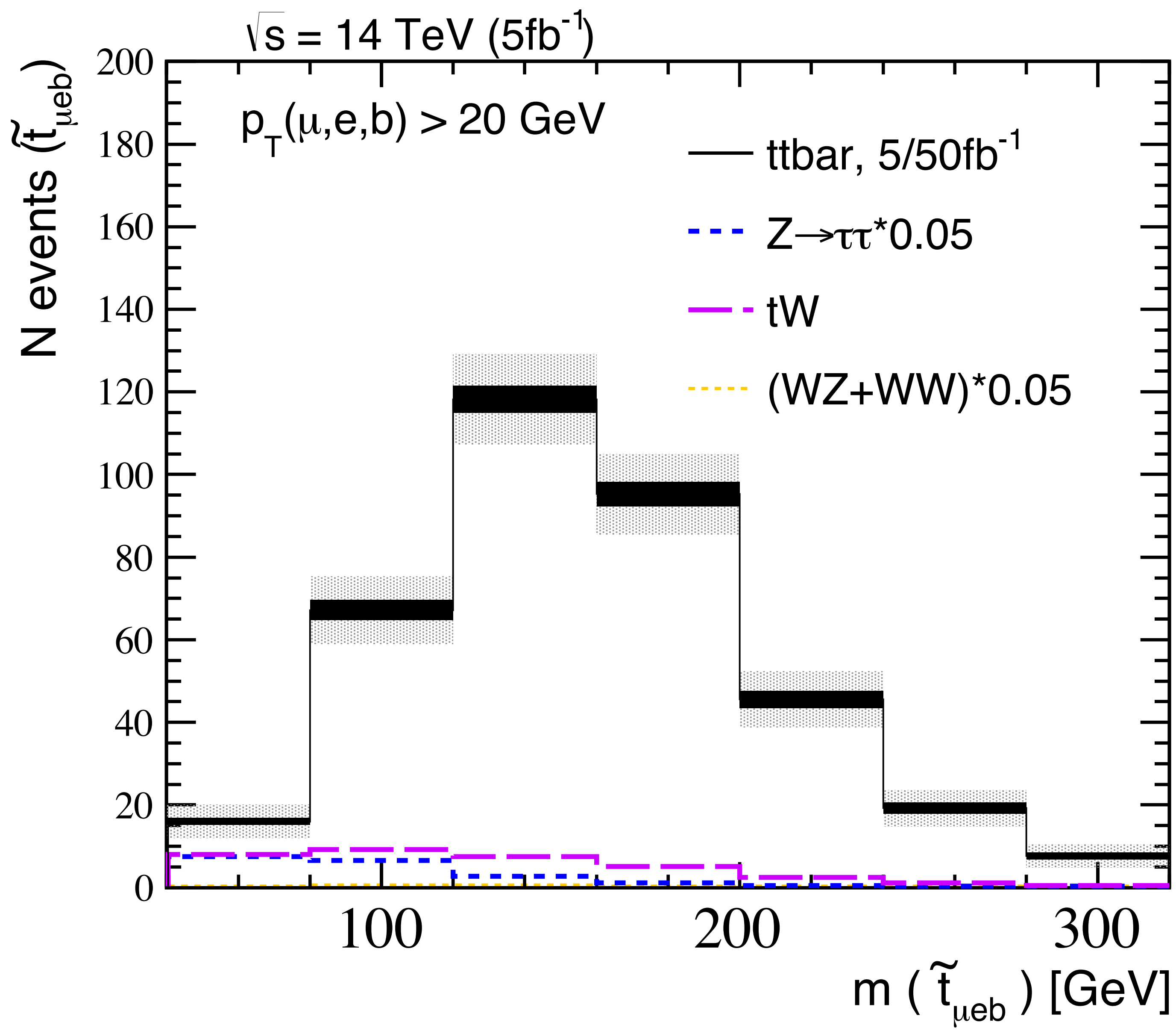
$$14\ TeV$$

$$\mu e b$$

N events expected

2017 - 5 ifb

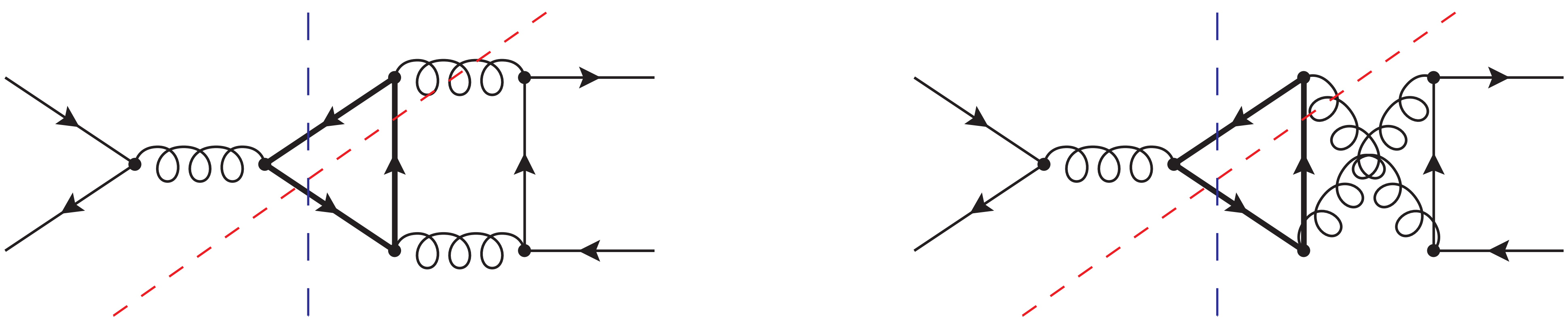
2030 - 50 ifb



leptonic asymmetries for LHCb
(all at 14 TeV)

Overview

$$\sigma_{(a)s} = \frac{1}{2}\int_0^1 d\cos\theta \left(\frac{d\sigma^{pp\to t\bar{t}X}}{d\cos\theta} \underset{(-)}{+} \frac{d\sigma^{pp\to \bar{t}tX}}{d\cos\theta} \right)$$



$$\sigma_a^{s(1)} = \frac{1}{2}\int_0^1 d\cos\theta \Bigg(\left(\mathcal{C}_{\text{left}} \frac{d\sigma_{\text{left}}(p_3,p_4)}{d\cos\theta} + \mathcal{C}_{\text{right}} \frac{d\sigma_{\text{right}}(p_3,p_4)}{d\cos\theta} \right) - \left(\mathcal{C}_{\text{left}} \frac{d\sigma_{\text{left}}(p_4,p_3)}{d\cos\theta} + \mathcal{C}_{\text{right}} \frac{d\sigma_{\text{right}}(p_4,p_3)}{d\cos\theta} \right) \Bigg)$$

Phys. Lett. B195(1987) 74 F. Halzen, P. Hoyer, and C. Kim
Nucl. Phys. B327 (1989) 49 P. Nason, S. Dawson, and R. K. Ellis
arXiv:hep-ph/9802268, arXiv:hep-ph/9807420 J.H.Kuhn, G. Rodrigo
… and many others since

Structure in perturbation theory

$$A_c = \frac{\alpha_s^3 \sigma_a^{s(1)} + \alpha_s^4 \sigma_a^{s(2)} + \alpha_s^2 \alpha_e \sigma_a^{e(1)} + \alpha_s^2 \alpha_w \sigma_a^{w(1)} + \cdots}{\alpha_s^2 \sigma_s^{s(0)} + \alpha_s^3 \sigma_s^{s(1)} + \alpha_s^4 \sigma_s^{s(2)} + \cdots},$$

$$= \alpha_s \frac{\sigma_a^{s(1)}}{\sigma_s^{s(0)}} + \alpha_e \frac{\sigma_a^{e(1)}}{\sigma_s^{s(0)}} + \alpha_w \frac{\sigma_a^{w(1)}}{\sigma_s^{s(0)}} + \alpha_s^2 \frac{1}{\sigma_s^{s(0)}} \left(\sigma_a^{s(2)} - \frac{\sigma_a^{s(1)} \sigma_s^{s(1)}}{\sigma_s^{s(0)}} \right) \cdots$$

Structure in perturbation theory

$$A_c = \frac{\alpha_s^3 \sigma_a^{s(1)} + \alpha_s^4 \sigma_a^{s(2)} + \alpha_s^2 \alpha_e \sigma_a^{e(1)} + \alpha_s^2 \alpha_w \sigma_a^{w(1)} + \cdots}{\alpha_s^2 \sigma_s^{s(0)} + \alpha_s^3 \sigma_s^{s(1)} + \alpha_s^4 \sigma_s^{s(2)} + \cdots},$$

$$= \alpha_s \frac{\sigma_a^{s(1)}}{\sigma_s^{s(0)}} + \alpha_e \frac{\sigma_a^{e(1)}}{\sigma_s^{s(0)}} + \alpha_w \frac{\sigma_a^{w(1)}}{\sigma_s^{s(0)}} + \alpha_s^2 \frac{1}{\sigma_s^{s(0)}} \left(\sigma_a^{s(2)} - \frac{\sigma_a^{s(1)} \sigma_s^{s(1)}}{\sigma_s^{s(0)}} \right) \cdots$$

Structure in perturbation theory

$$A_c = \frac{\alpha_s^3 \sigma_a^{s(1)} + \alpha_s^4 \sigma_a^{s(2)} + \alpha_s^2 \alpha_e \sigma_a^{e(1)} + \alpha_s^2 \alpha_w \sigma_a^{w(1)} + \cdots}{\alpha_s^2 \sigma_s^{s(0)} + \alpha_s^3 \sigma_s^{s(1)} + \alpha_s^4 \sigma_s^{s(2)} + \cdots},$$

$$= \alpha_s \frac{\sigma_a^{s(1)}}{\sigma_s^{s(0)}} + \alpha_e \frac{\sigma_a^{e(1)}}{\sigma_s^{s(0)}} + \alpha_w \frac{\sigma_a^{w(1)}}{\sigma_s^{s(0)}} + \alpha_s^2 \frac{1}{\sigma_s^{s(0)}} \left(\sigma_a^{s(2)} - \frac{\sigma_a^{s(1)} \sigma_s^{s(1)}}{\sigma_s^{s(0)}} \right) \cdots$$

NLO in production and decay (MCFM)
arXiv:1204.1513 J. Campbell and R. K. Ellis

Structure in perturbation theory

$$A_c = \frac{\alpha_s^3 \sigma_a^{s(1)} + \alpha_s^4 \sigma_a^{s(2)} + \alpha_s^2 \alpha_e \sigma_a^{e(1)} + \alpha_s^2 \alpha_w \sigma_a^{w(1)} + \cdots}{\alpha_s^2 \sigma_s^{s(0)} + \alpha_s^3 \sigma_s^{s(1)} + \alpha_s^4 \sigma_s^{s(2)} + \cdots},$$

$$= \alpha_s \frac{\sigma_a^{s(1)}}{\sigma_s^{s(0)}} + \alpha_e \frac{\sigma_a^{e(1)}}{\sigma_s^{s(0)}} + \alpha_w \frac{\sigma_a^{w(1)}}{\sigma_s^{s(0)}} + \alpha_s^2 \frac{1}{\sigma_s^{s(0)}} \left(\sigma_a^{s(2)} - \frac{\sigma_a^{s(1)} \sigma_s^{s(1)}}{\sigma_s^{s(0)}} \right) \cdots$$

$$R_{q\bar{q}}^{\mathrm{QED}}(\mu) = \frac{36 Q_q Q_t \alpha_e}{5\alpha_s}, \quad R_{qg}^{\mathrm{QED}}(\mu) = \frac{24 Q_q Q_t \alpha_e}{5\alpha_s}$$

Apply rescaling of couplings and colour factors

NLO in production and decay (MCFM)
arXiv:1204.1513 J. Campbell and R. K. Ellis

Single-lepton asymmetry

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

$$2.0 < \eta(l,b) < 4.5$$
$$p_T(l/b) > 20/60 \text{ GeV}$$
$$\Delta R(l^\pm, \text{jet}) \geq 0.5$$

Signal contribution to **numerator**
Computed with NNPDF2.3 NLO as 119 PDFs

N^l (fb)		$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$
$\mathcal{O}(\alpha_s^3)$	$u\bar{u}$	41.85	30.90	24.37
	$d\bar{d}$	18.09	12.87	9.91
	ug	1.90	1.22	0.85
	dg	0.72	0.45	0.34
$\mathcal{O}(\alpha_s^2 \alpha_e)$	Total	7.05	5.79	4.97
Total		69.60	51.23	40.44

Single-lepton asymmetry

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

$$2.0 < \eta(l,b) < 4.5$$
$$p_T(l/b) > 20/60 \text{ GeV}$$
$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$

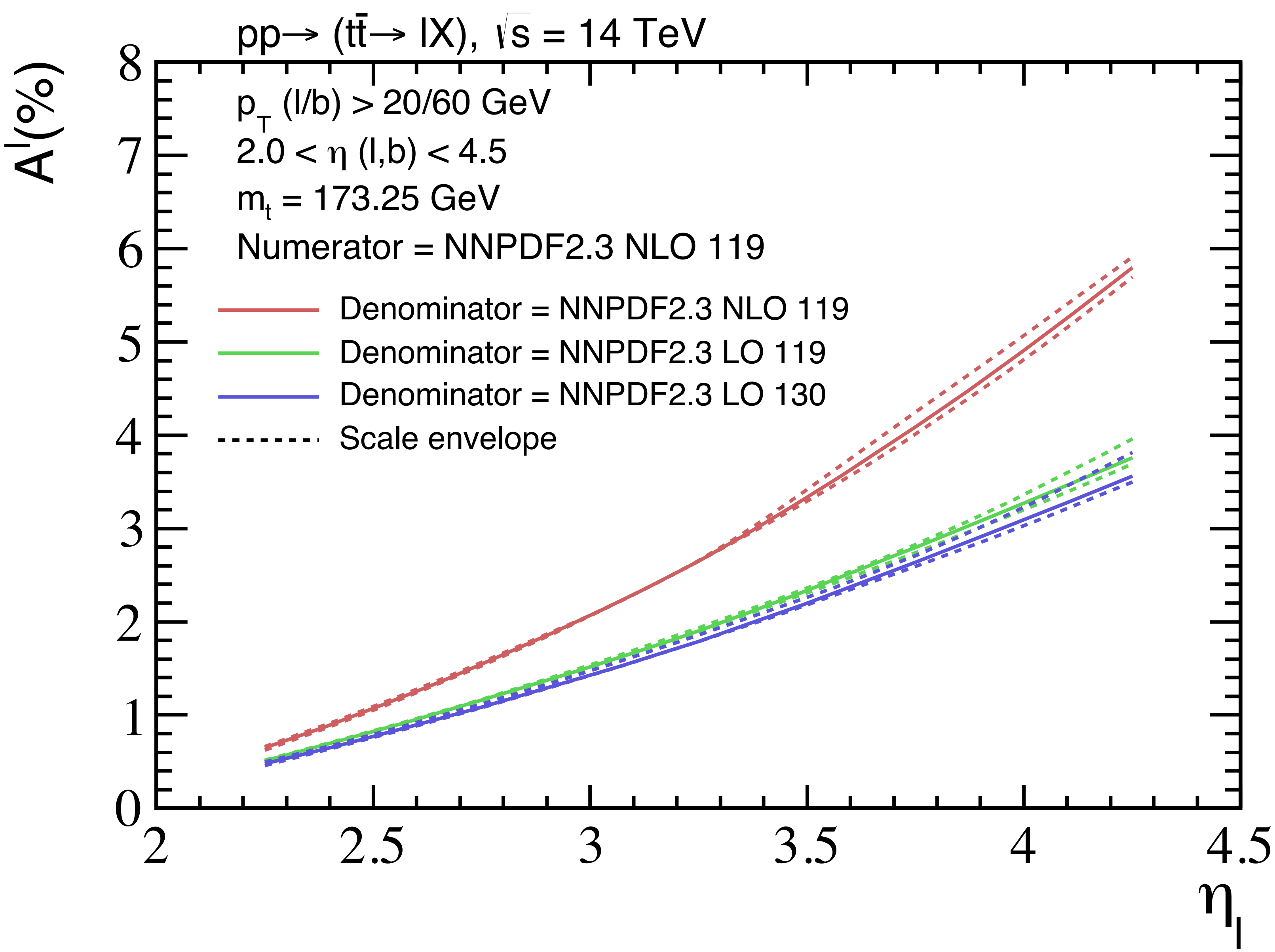
Signal contribution to **denominator**
Computed with various LO/NLO NNPDF2.3 PDFs

	D^l (fb), 14 TeV			
PDF	$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$	A^l (%)
NLO 119	4626	3512	2742	1.48 (2)
LO 119	6225	4663	3586	1.12 (2)
LO 130	6761	4961	3752	1.05 (3)

Single-lepton asymmetry

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

$$2.0 < \eta(l,b) < 4.5$$
$$p_T(l/b) > 20/60 \text{ GeV}$$
$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$

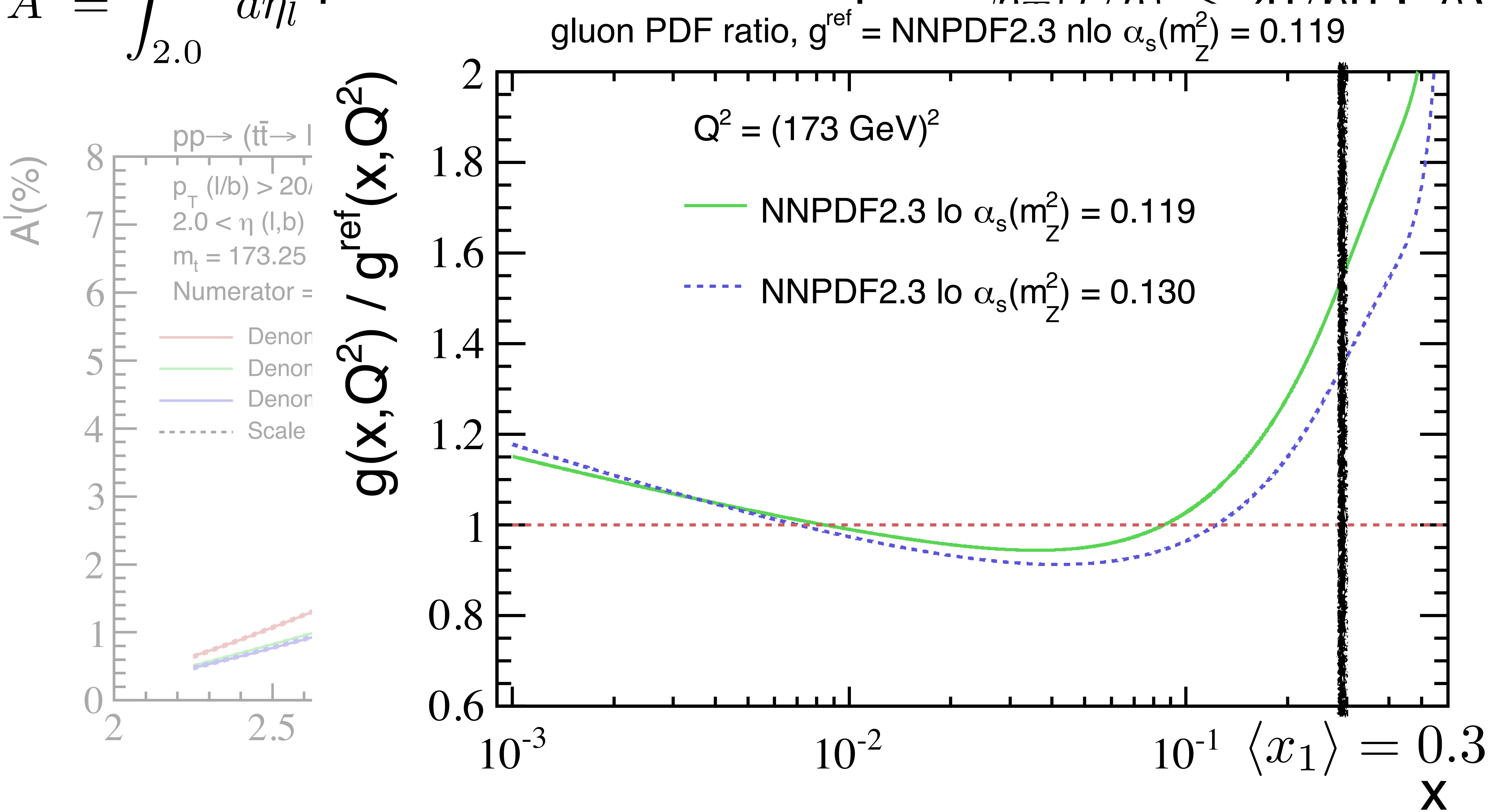


Single-lepton asymmetry

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l \right)$$

$$2.0 < \eta(l,b) < 4.5$$

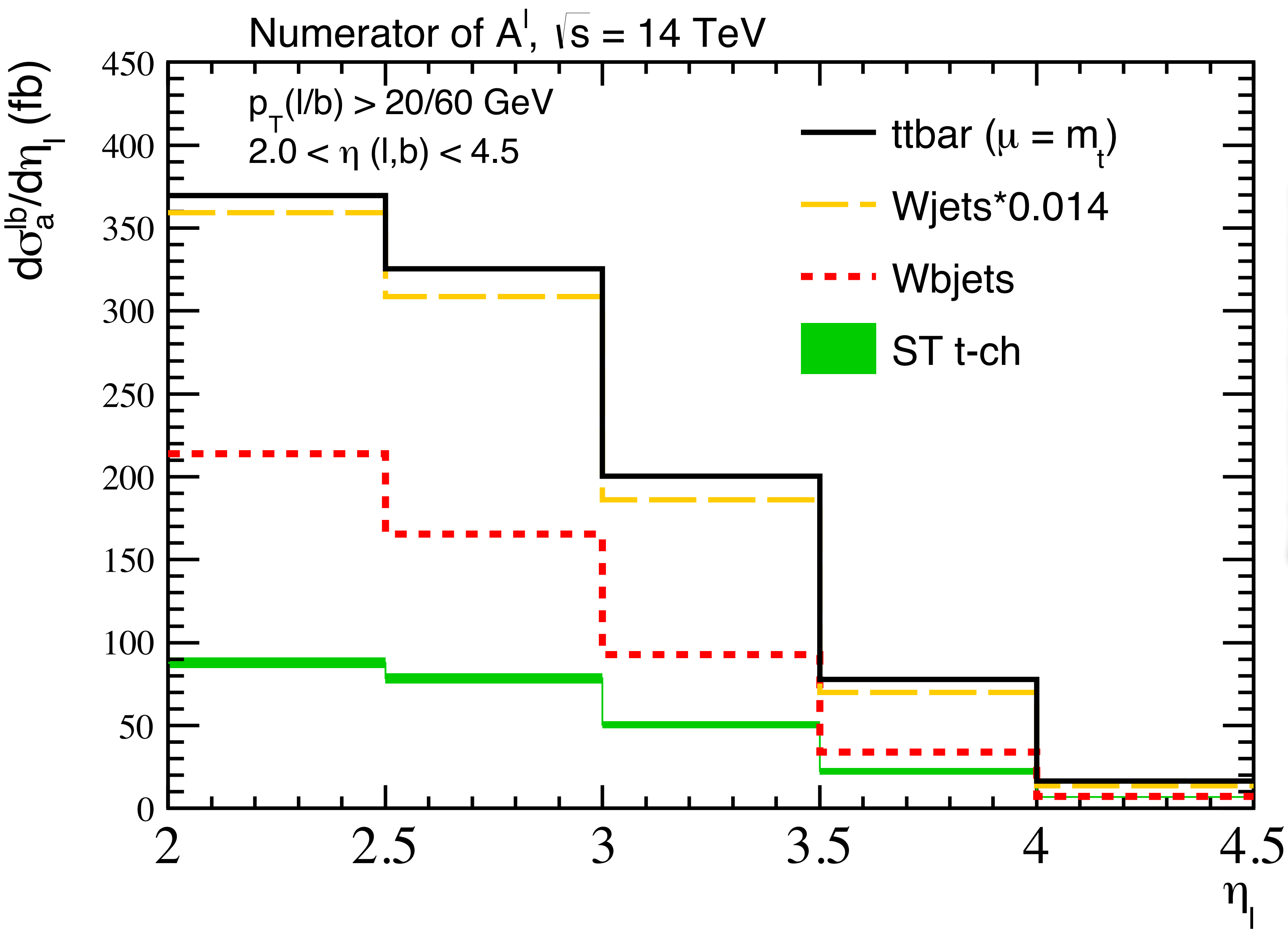
$$p_T(l/b) > 20/60\ \mathrm{GeV}$$



What about backgrounds!?

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+b}/d\eta_l - d\sigma^{l^-b}/d\eta_l}{d\sigma^{l^+b}/d\eta_l + d\sigma^{l^-b}/d\eta_l} \right)$$

$$2.0 < \eta(l,b) < 4.5$$
$$p_T(l/b) > 20/60 \text{ GeV}$$
$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$



Fit backgrounds experimentally:

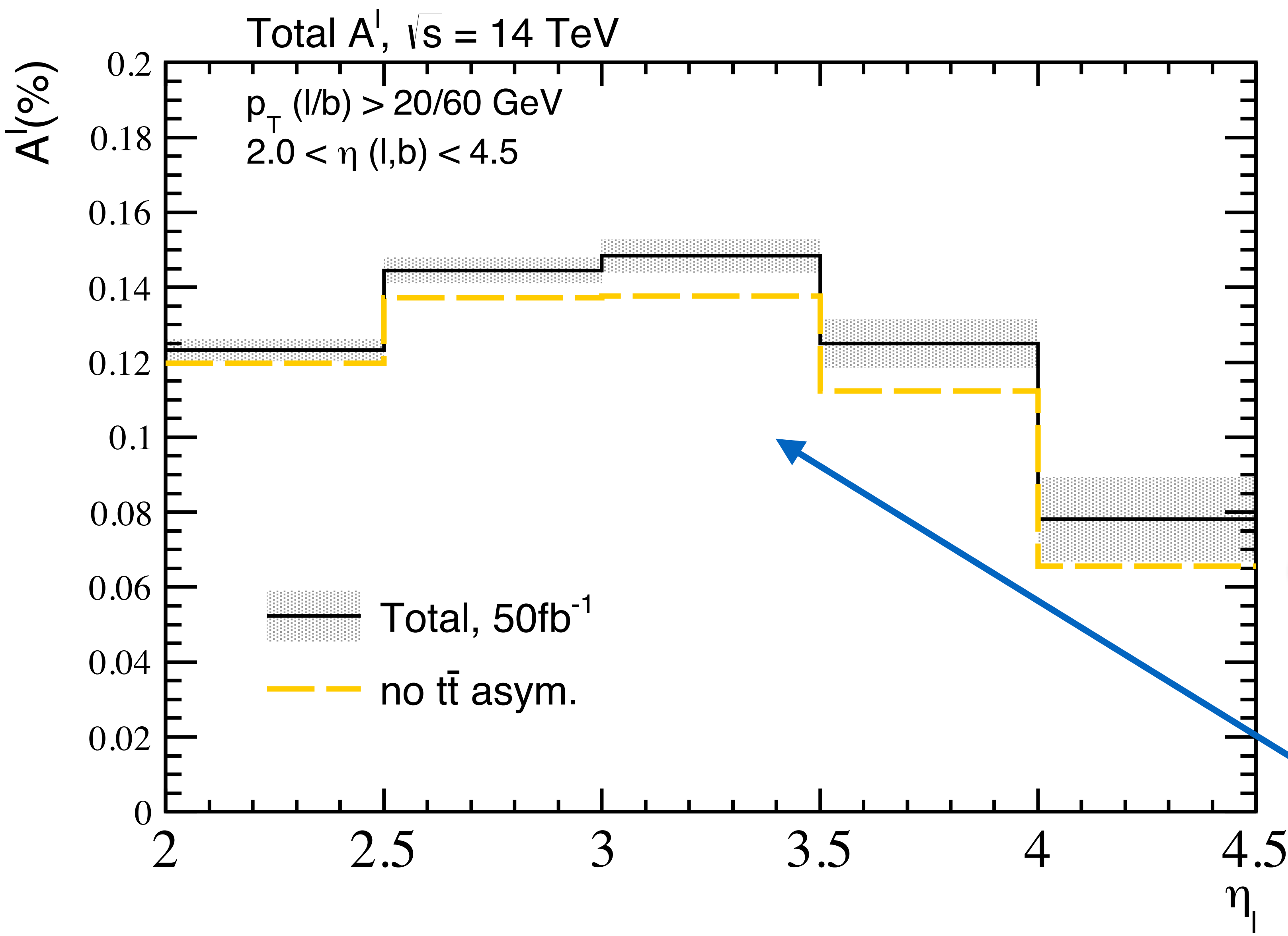
$l^{\pm}j, l^{\pm}bj, l^{\pm}bb$

control channels

What about backgrounds!?

$$A^l = \int_{2.0}^{4.5} d\eta_l \left(\frac{d\sigma^{l^+ b}/d\eta_l - d\sigma^{l^- b}/d\eta_l}{d\sigma^{l^+ b}/d\eta_l + d\sigma^{l^- b}/d\eta_l} \right)$$

$$2.0 < \eta(l, b) < 4.5$$
$$p_T(l/b) > 20/60 \text{ GeV}$$
$$\Delta R(l^\pm, \text{jet}) \geq 0.5$$



Statistical uncertainty only

$$\chi^2_{\text{no}\, t\bar{t}\, \text{asym}} = 13.76$$

Excluded beyond 3σ

Sensitivity in bins

$$2.5 < \eta_l < 4.0$$

Di-lepton asymmetry

$$A_{fb}^{ll} = \int d\Delta_y \frac{\left(d\sigma^{\mu eb}(\Delta_y > 0) - d\sigma^{\mu eb}(\Delta_y < 0)\right)/d\Delta_y}{d\sigma^{\mu eb}/d\Delta_y}$$

$$2.0 < \eta(e,\mu,b) < 4.5$$
$$p_T(e,\mu,b) > 20 \text{ GeV}$$
$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$

Signal contribution to **numerator**
Computed with NNPDF2.3 NLO as 119 PDFs

N_{fb}^{ll} (fb)		$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$
$\mathcal{O}(\alpha_s^3)$	$u\bar{u}$	0.889	0.659	0.490
	$d\bar{d}$	0.319	0.232	0.176
	ug	0.095	0.070	0.045
	dg	0.031	0.021	0.013
$\mathcal{O}(\alpha_s^2\alpha_e)$	Total	0.163	0.134	0.107
Total		1.498	1.116	0.832

Di-lepton asymmetry

$$A_{fb}^{ll} = \int d\Delta_y \frac{\left(d\sigma^{\mu eb}(\Delta_y > 0) - d\sigma^{\mu eb}(\Delta_y < 0)\right)/d\Delta_y}{d\sigma^{\mu eb}/d\Delta_y}$$

$$2.0 < \eta(e,\mu,b) < 4.5$$
$$p_T(e,\mu,b) > 20 \text{ GeV}$$
$$\Delta R(l^\pm, \text{jet}) \geq 0.5$$

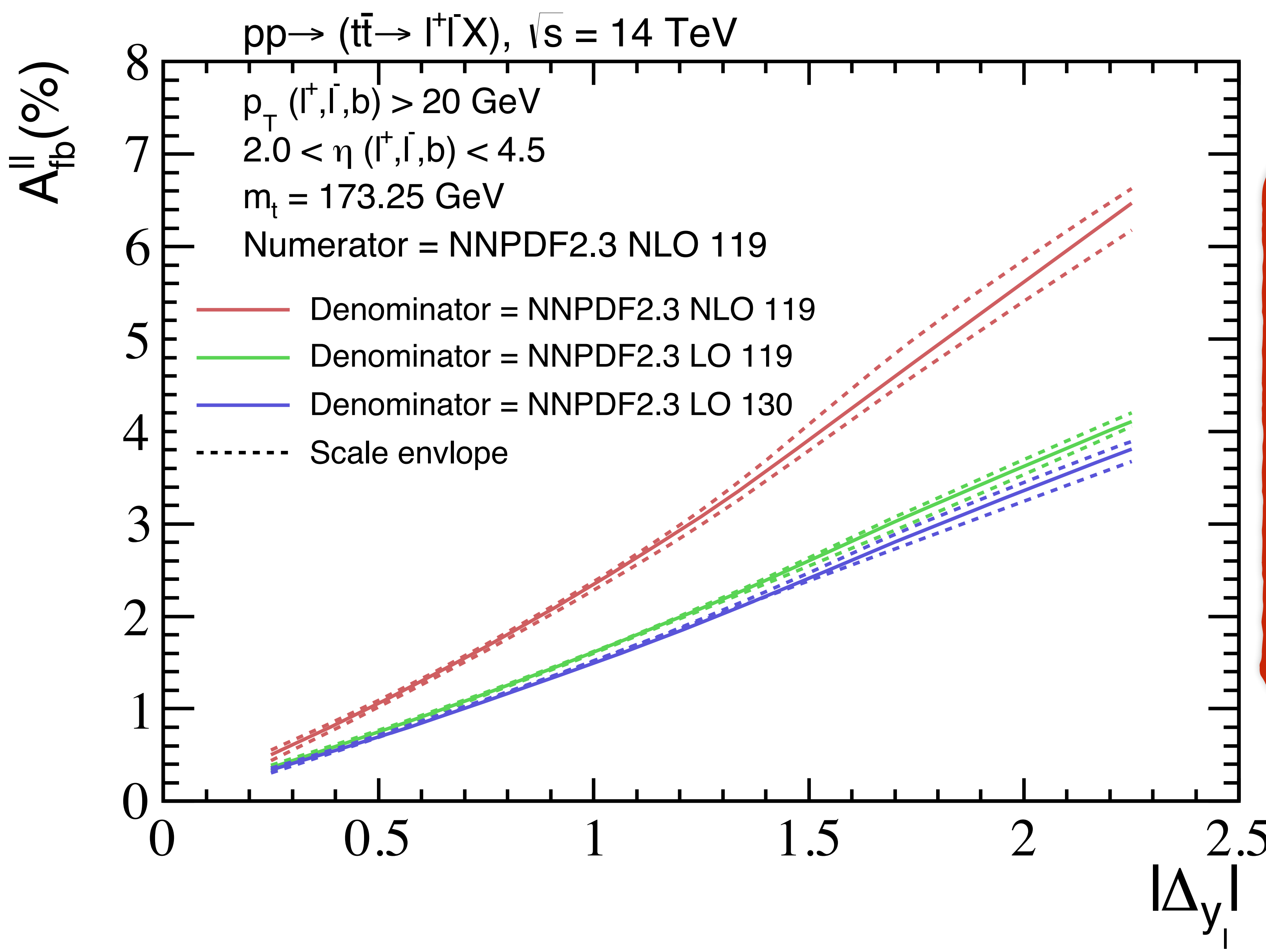
Signal contribution to **denominator**
Computed with various LO/NLO NNPDF2.3 PDFs

	D_{fb}^{ll} (fb), 14 TeV			
PDF	$\mu = m_t/2$	$\mu = m_t$	$\mu = 2m_t$	A_{fb}^{ll} (%)
NLO 119	110.4	85.0	67.4	1.30 (7)
LO 119	160.7	120.7	93.3	0.91 (2)
LO 130	176.6	130.0	98.8	0.85 (1)

Di-lepton asymmetry

$$A^{ll}_{fb} = \int d\Delta_y \frac{\left(d\sigma^{\mu e b}(\Delta_y > 0) - d\sigma^{\mu e b}(\Delta_y < 0)\right)/d\Delta_y}{d\sigma^{\mu e b}/d\Delta_y}$$

$$2.0 < \eta(e, \mu, b) < 4.5$$
$$p_T(e, \mu, b) > 20 \text{ GeV}$$
$$\Delta R(l^{\pm}, \text{jet}) \geq 0.5$$



Statistical uncertainty only

expect ~6k events

$$A \simeq 1.30\%(theo)$$
$$\delta A \simeq \pm 1.30\%(stat)$$

not significant..

Conclusion

- LHCb can measure ttbar cross section
    - first of its kind at high pseudorapidity
- Charge asymmetry measurements possible
    - single-lepton channel promising
    - experimentally still challenging…
    - a background fit in many channels necessary

Thank you for your attention!

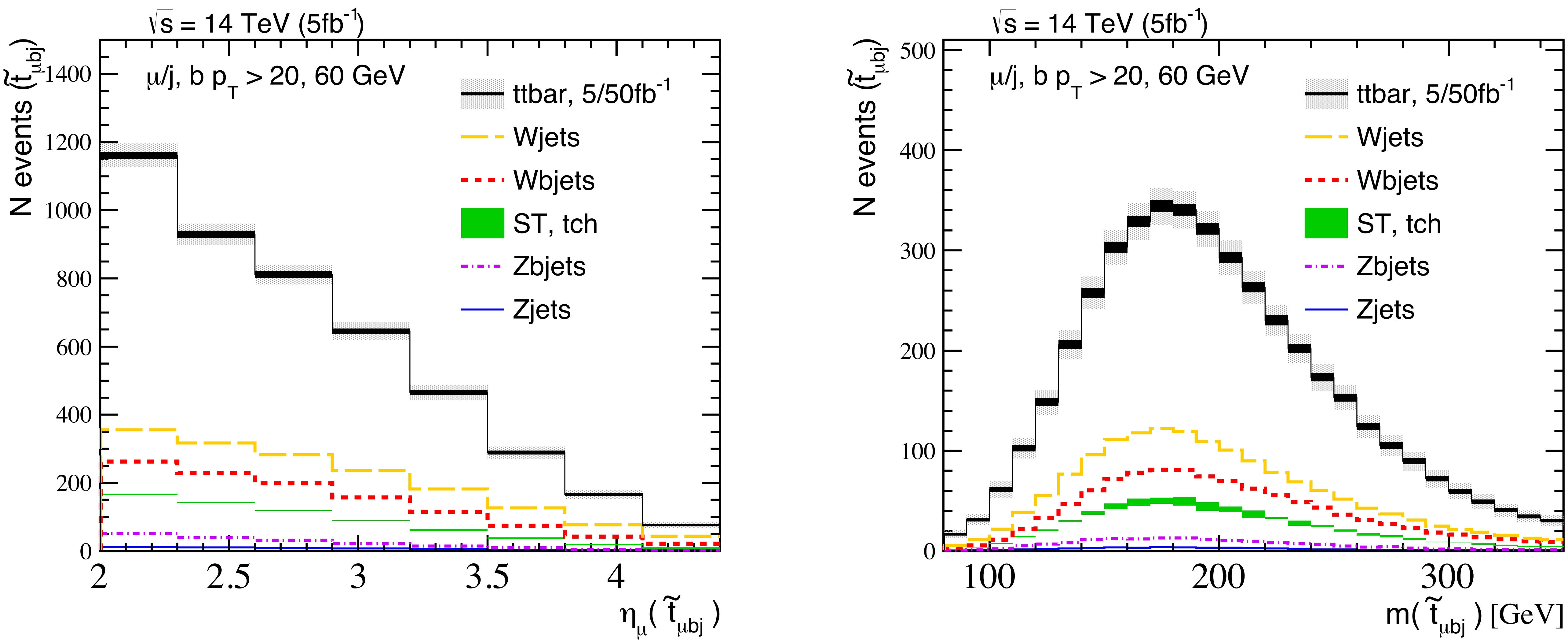
Feasibility - event yield

Some other channels (loose cuts)

- generate ttbar (**POWHEG**) and match to parton shower (**Pythia8176**)
- build R = 0.5 anti-kt jets (j)
- truth match parton level b-quarks to jets within dR < 0.5 (b)
- apply loose cuts: l(e,mu) pT > 4 GeV and j/b pT > 20 GeV
- apply acceptance cuts: 2.0 < l, j/b eta < 4.5

Data	1fb^{-1}	2fb^{-1}	$5/50\text{fb}^{-1}$
$d\sigma(\text{fb})$	7 TeV	8 TeV	14 TeV
lb	285 ± 52	504 ± 94	4366 ± 663
lbj	97 ± 21	198 ± 35	2335 ± 323
lbb	32 ± 6	65 ± 12	870 ± 116
$lbbj$	10 ± 2	26 ± 4	487 ± 76
l^+l^-	44 ± 9	79 ± 15	635 ± 109
l^+l^-b	19 ± 4	39 ± 8	417 ± 79

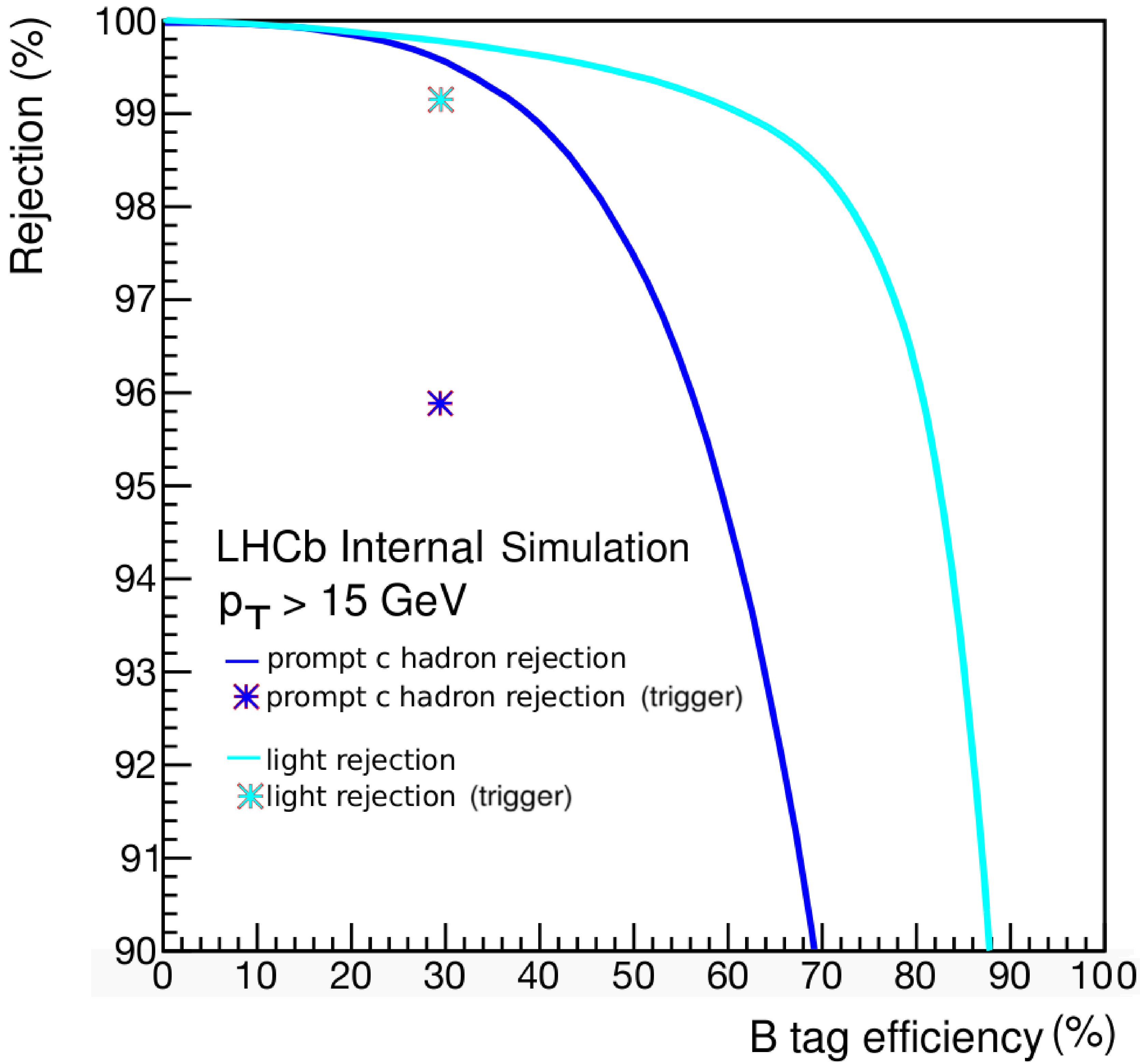
Single-lepton 14 TeV (lbj)



$$14\ TeV$$

$$l^{\pm}bj$$

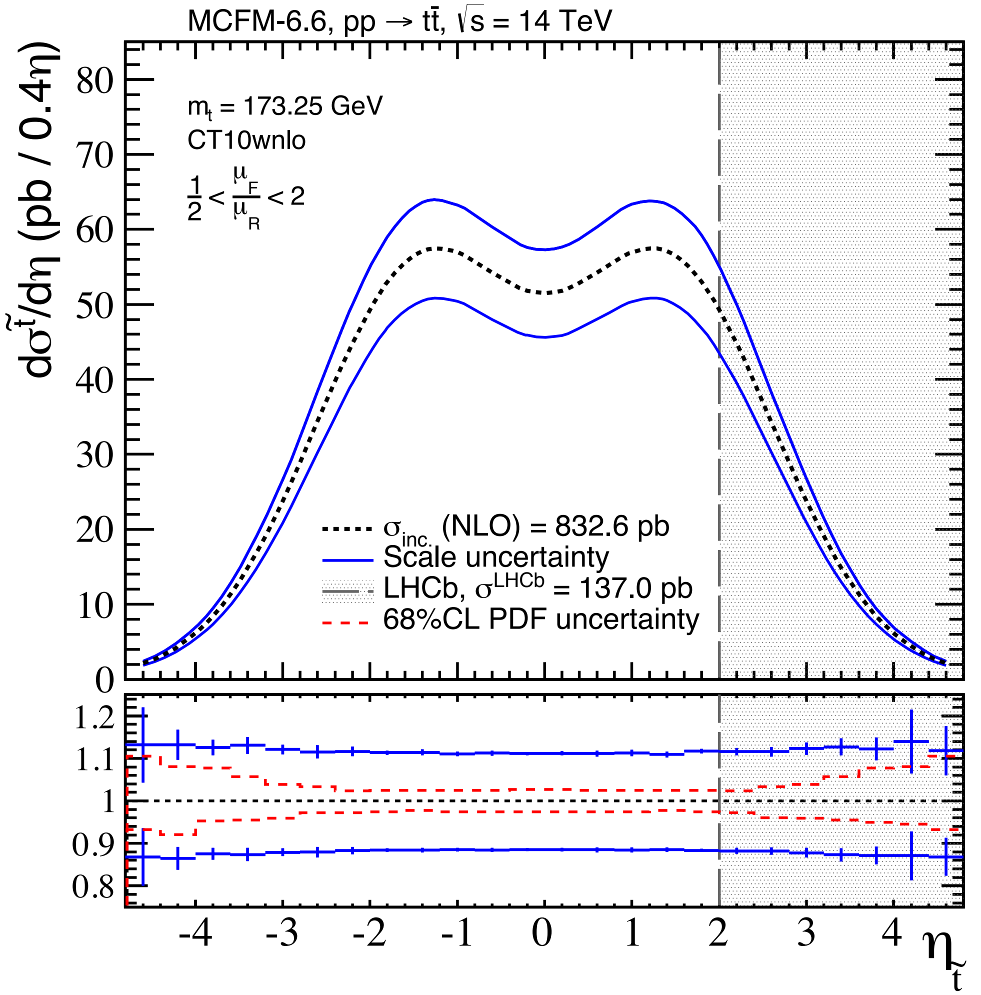
LHCb b-tagging



Theoretical systematics

$$\frac{d\sigma^{\tilde{t}}}{dX} = \frac{1}{2}\left(\frac{d\sigma^{t}}{dX} + \frac{d\sigma^{\bar{t}}}{dX}\right)$$

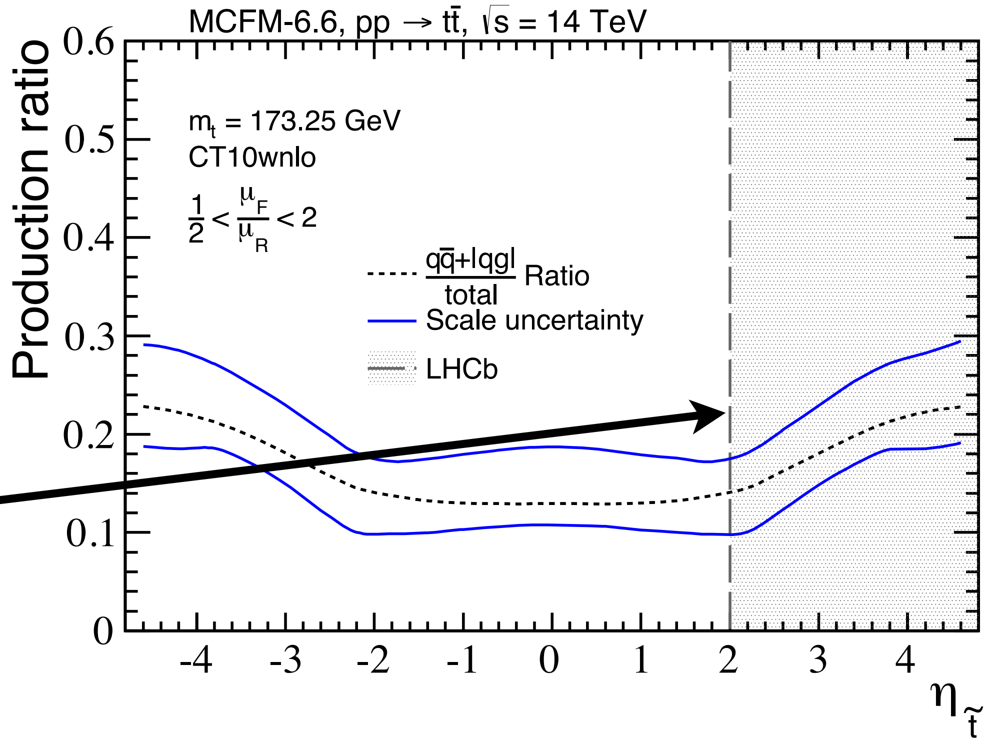
$$\sigma^{\mathrm{LHCb}} = \int_{\eta=2} \frac{d\sigma^{\tilde{t}}}{d\eta}$$



Production mechanism ratio:

$$\frac{q\bar{q} + |qg|}{total}$$

LHCb probes unique region



Theoretical systematics

Scale

$$\sigma = \int dx_a dx_b f_a(x_a, \mu_F^2) f_b(x_b, \mu_F^2) \hat{\sigma}(\mu_f, \mu_R, m^2, \beta)$$

PDF

Strong coupling

$$\hat{\sigma}(\beta) = \frac{\alpha_s^2}{m^2} \left(\sigma_{ij}^{(0)} + \alpha_s \sigma_{ij}^{(1)} + \alpha_s^2 \sigma_{ij}^{(2)} + \mathcal{O}(\alpha_s^3) \right)$$

Top mass

$$\beta = \sqrt{1 - 4m^2/s}$$

$$\frac{1}{2} < \frac{\mu_F}{\mu_R} < 2$$

$$\delta \text{PDF} = 1\sigma \text{CL}$$

$$\alpha_s(M_Z) = 0.1184 \pm 0.0007$$

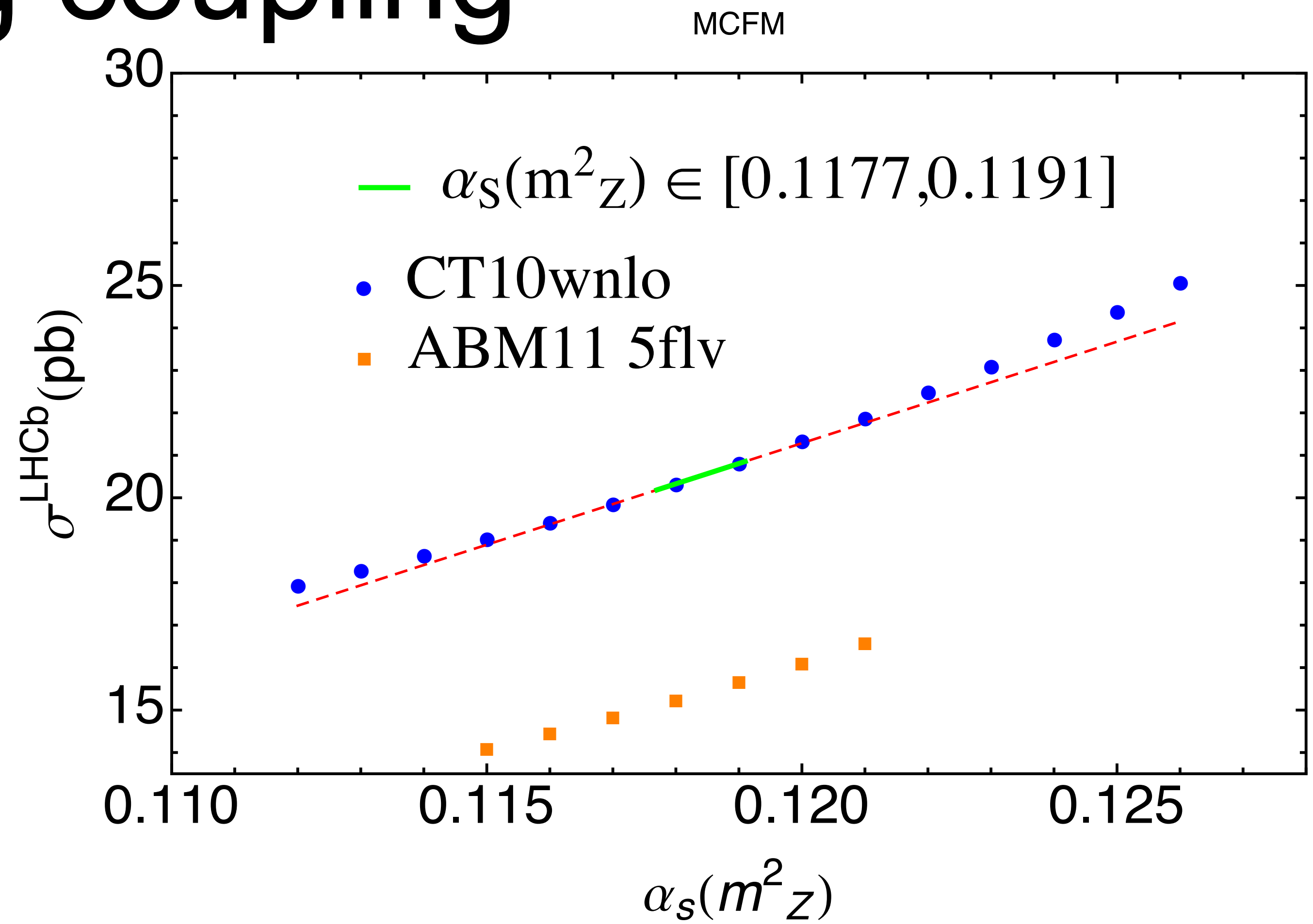
$$\delta m_t = 1.5 \text{ GeV}$$

strong coupling

σ^{LHCb} vs. $\alpha_s(M_Z)$

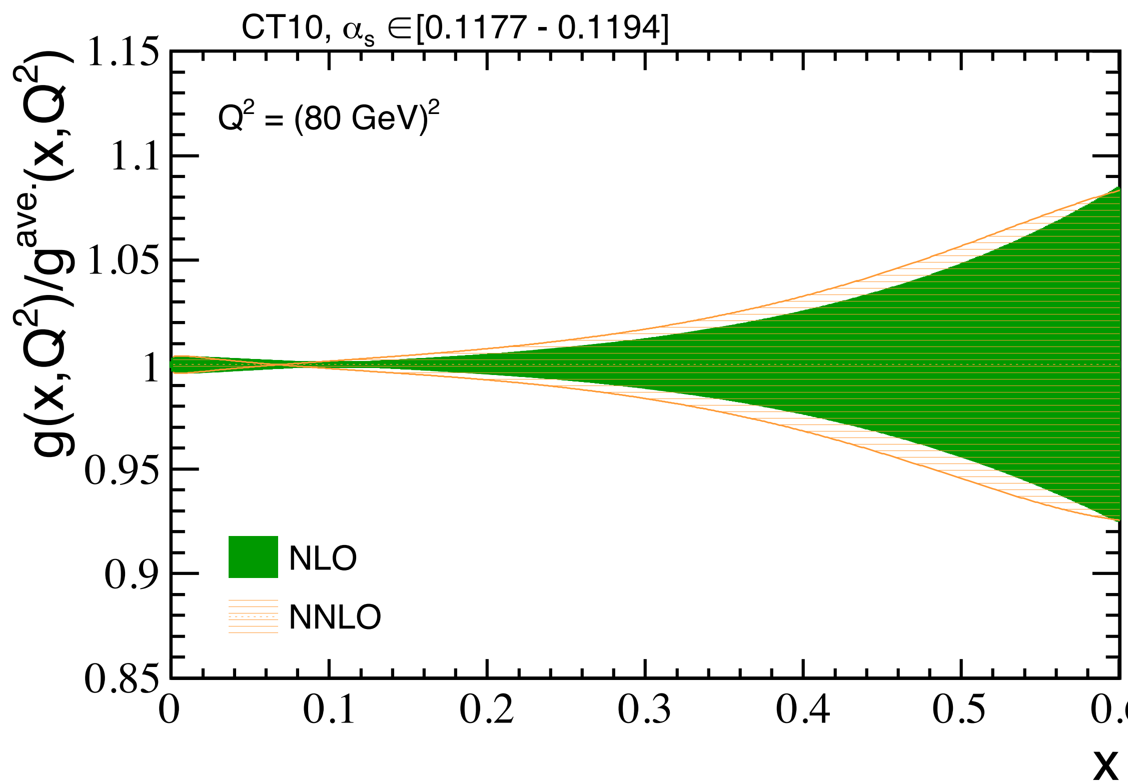
Current PDG value

$$\alpha_s(M_Z) = 0.1184 \pm 0.0007$$



gluon PDF uncertainty for $\delta\alpha_s$

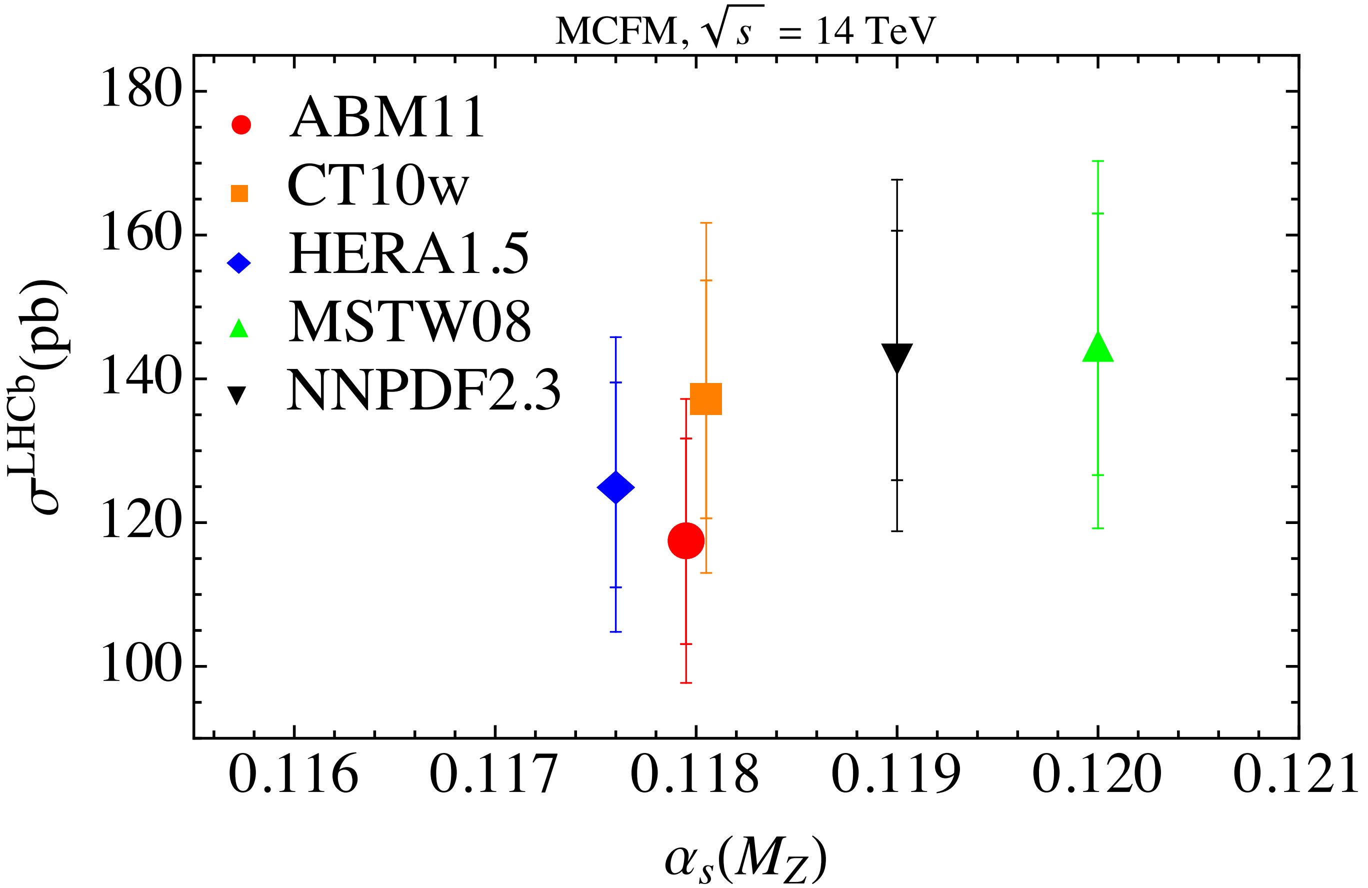
$$\delta\alpha_s \rightarrow \delta\sigma^{\text{LHCb}} = 1.3\%$$



Order	PDF	σ(pb)	δ_{scale} (pb)	δ_{PDF} (pb)	δ_{α_s} (pb)	δ_{m_t} (pb)	δ_{total} (pb)
NNLO*(inc.)	ABM	832.0	+18.7 (+2.2%) −27.4 (−3.3%)	+25.1 (+3.0%) −25.1 (−3.0%)	+0.0 (+0.0%) −0.0 (−0.0%)	+34.9 (+4.2%) −33.7 (−4.1%)	+61.7 (+7.4%) −69.7 (−8.4%)
NLO(inc.)	ABM	771.9	+91.0 (+11.8%) −92.4 (−12.0%)	+9.4 (+1.2%) −9.4 (−1.2%)	+0.0 (+0.0%) −0.0 (−0.0%)	+32.3 (+4.2%) −31.9 (−4.1%)	+124.7 (+16.1%) −125.7 (−16.3%)
NLO(LHCb)	ABM	117.2	+14.5 (+12.3%) −14.1 (−12.0%)	+2.0 (+1.7%) −2.0 (−1.7%)	+0.0 (+0.0%) −0.0 (−0.0%)	+5.2 (+4.4%) −5.1 (−4.3%)	+20.0 (+17.1%) −19.5 (−16.7%)
NNLO*(inc.)	CT10	952.8	+23.3 (+2.4%) −34.5 (−3.6%)	+22.4 (+2.3%) −19.9 (−2.1%)	+14.0 (+1.5%) −14.0 (−1.5%)	+39.2 (+4.1%) −37.8 (−4.0%)	+70.6 (+7.4%) −79.5 (−8.3%)
NLO(inc.)	CT10	832.6	+97.0 (+11.7%) −96.7 (−11.6%)	+19.6 (+2.4%) −20.2 (−2.4%)	+9.2 (+1.1%) −9.2 (−1.1%)	+34.0 (+4.1%) −33.3 (−4.0%)	+137.4 (+16.5%) −136.6 (−16.4%)
NLO(LHCb)	CT10	137.0	+16.7 (+12.2%) −16.4 (−12.0%)	+5.0 (+3.6%) −4.6 (−3.4%)	+1.8 (+1.3%) −1.8 (−1.3%)	+5.9 (+4.3%) −5.8 (−4.2%)	+24.7 (+18.0%) −24.0 (−17.5%)
NNLO*(inc.)	HERA	970.5	+22.1 (+2.3%) −22.0 (−2.3%)	+15.7 (+1.6%) −25.7 (−2.6%)	+12.8 (+1.3%) −12.8 (−1.3%)	+39.6 (+4.1%) −38.4 (−4.0%)	+66.6 (+6.9%) −70.0 (−7.2%)
NLO(inc.)	HERA	804.2	+91.9 (+11.4%) −87.6 (−10.9%)	+16.1 (+2.0%) −21.9 (−2.7%)	+5.3 (+0.7%) −5.3 (−0.7%)	+33.4 (+4.1%) −32.4 (−4.0%)	+129.3 (+16.1%) −127.1 (−15.8%)
NLO(LHCb)	HERA	124.7	+14.8 (+11.8%) −13.7 (−11.0%)	+3.0 (+2.4%) −3.0 (−2.4%)	+1.1 (+0.9%) −1.1 (−0.9%)	+5.5 (+4.4%) −5.3 (−4.3%)	+21.1 (+16.9%) −19.9 (−15.9%)
NNLO*(inc.)	MSTW	953.6	+22.7 (+2.4%) −33.9 (−3.6%)	+16.2 (+1.7%) −17.8 (−1.9%)	+12.8 (+1.3%) −12.8 (−1.3%)	+39.1 (+4.1%) −37.9 (−4.0%)	+66.9 (+7.0%) −77.7 (−8.1%)
NLO(inc.)	MSTW	885.6	+107.2 (+12.1%) −105.7 (−11.9%)	+16.0 (+1.8%) −19.4 (−2.2%)	+10.1 (+1.1%) −10.1 (−1.1%)	+36.2 (+4.1%) −35.3 (−4.0%)	+148.1 (+16.7%) −147.3 (−16.6%)
NLO(LHCb)	MSTW	144.4	+18.6 (+12.8%) −17.8 (−12.3%)	+3.5 (+2.4%) −3.9 (−2.7%)	+1.9 (+1.3%) −1.9 (−1.3%)	+6.2 (+4.3%) −6.1 (−4.2%)	+25.9 (+18.0%) −25.2 (−17.5%)
NNLO*(inc.)	NNPDF	977.5	+23.6 (+2.4%) −35.4 (−3.6%)	+16.4 (+1.7%) −16.4 (−1.7%)	+12.2 (+1.3%) −12.2 (−1.3%)	+40.4 (+4.1%) −39.1 (−4.0%)	+68.9 (+7.0%) −80.0 (−8.1%)
NLO(inc.)	NNPDF	894.5	+107.6 (+12.0%) −101.0 (−11.3%)	+12.8 (+1.4%) −12.8 (−1.4%)	+9.9 (+1.1%) −9.9 (−1.1%)	+36.6 (+4.1%) −35.8 (−4.0%)	+147.6 (+16.5%) −140.3 (−15.7%)
NLO(LHCb)	NNPDF	142.5	+18.1 (+12.7%) −16.6 (−11.7%)	+3.0 (+2.1%) −3.0 (−2.1%)	+2.0 (+1.4%) −2.0 (−1.4%)	+6.2 (+4.4%) −6.1 (−4.3%)	+25.2 (+17.7%) −23.7 (−16.6%)

Summary of theory systematics (NLO)

$$\delta_{\text{total}} = \delta_{\text{scale}} + (\delta^2_{\text{PDF}} + \delta^2_{\alpha_s} + \delta^2_{m_t})^{\frac{1}{2}}$$



$$\delta_X^{\text{ratio}} = \frac{\delta_X^{\text{LHCb}}}{\delta_X^{NLO}}$$

PDF	$\delta^{\text{ratio}}_{\text{scale}}$	$\delta^{\text{ratio}}_{\text{PDF}}$	$\delta^{\text{ratio}}_{\alpha_s}$	$\delta^{\text{ratio}}_{m_t}$	$\delta^{\text{ratio}}_{\text{total}}$
ABM	$^{+1.05}_{-1.00}$	$^{+1.40}_{-1.40}$	$^{+0.00}_{-0.00}$	$^{+1.05}_{-1.05}$	$^{+1.06}_{-1.02}$
CT10	$^{+1.05}_{-1.03}$	$^{+1.55}_{-1.40}$	$^{+1.20}_{-1.20}$	$^{+1.06}_{-1.05}$	$^{+1.09}_{-1.07}$
HERA	$^{+1.04}_{-1.01}$	$^{+1.19}_{-0.90}$	$^{+1.33}_{-1.33}$	$^{+1.07}_{-1.06}$	$^{+1.05}_{-1.01}$
MSTW	$^{+1.06}_{-1.03}$	$^{+1.35}_{-1.23}$	$^{+1.13}_{-1.13}$	$^{+1.05}_{-1.06}$	$^{+1.07}_{-1.05}$
NNPDF	$^{+1.05}_{-1.03}$	$^{+1.45}_{-1.45}$	$^{+1.27}_{-1.27}$	$^{+1.07}_{-1.07}$	$^{+1.07}_{-1.06}$

Constraining the gluon PDF

Perform a bayesian reweighting based on statistical inference.
arXiv:1012.0836 NNPDF collaboration
arXiv:1205.4024 G. Watt, R. S. Thorne, applied technique to MSTW hessian set

I apply the technique to CT10w and NNPDF2.3 NLO sets

Recipe for Hessian reweighting

1) Calculate observables from eigenvector set

$$\{X_0(\mathcal{S}_0), X_1^-(\mathcal{S}_1^-), X_1^+(\mathcal{S}_1^+), ...X_N^-(\mathcal{S}_N^-), X_N^+(\mathcal{S}_N^+)\}$$

2) Generate random observables from these (storing random numbers)

$$X(\mathcal{S}_k) = X(\mathcal{S}_0) + \sum_{j=1}^{N}[X(\mathcal{S}_j^{\pm}) - X(\mathcal{S}_0)]|R_{kj}|$$

3) Apply a reweighting based on a 'measured' observable (e.g. cross-section)

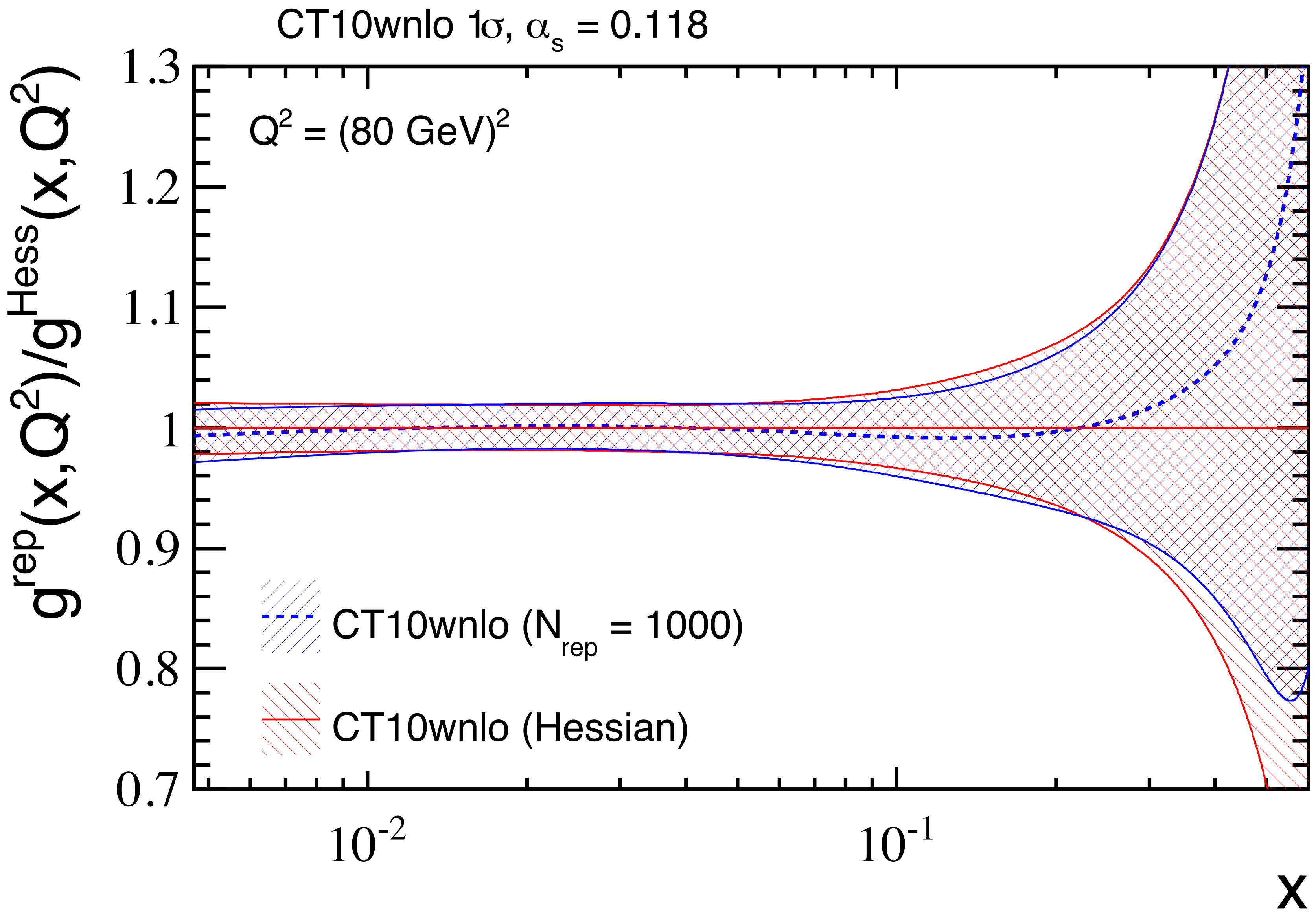
$$W_k(\chi_k^2) = (\chi_k^2)^{\frac{1}{2}(N_{pts.}-1)}\exp(-\frac{1}{2}\chi_k^2)$$

4) Apply these weights to the other observables (gluon PDF, ttbar asymmetry etc.)

Follow the recipe - steps 1, 2

1) Choose observable as evolved gluon PDF, $g^{\mathrm{Hess}}(x, [Q = 80 \text{ GeV}]^2)$

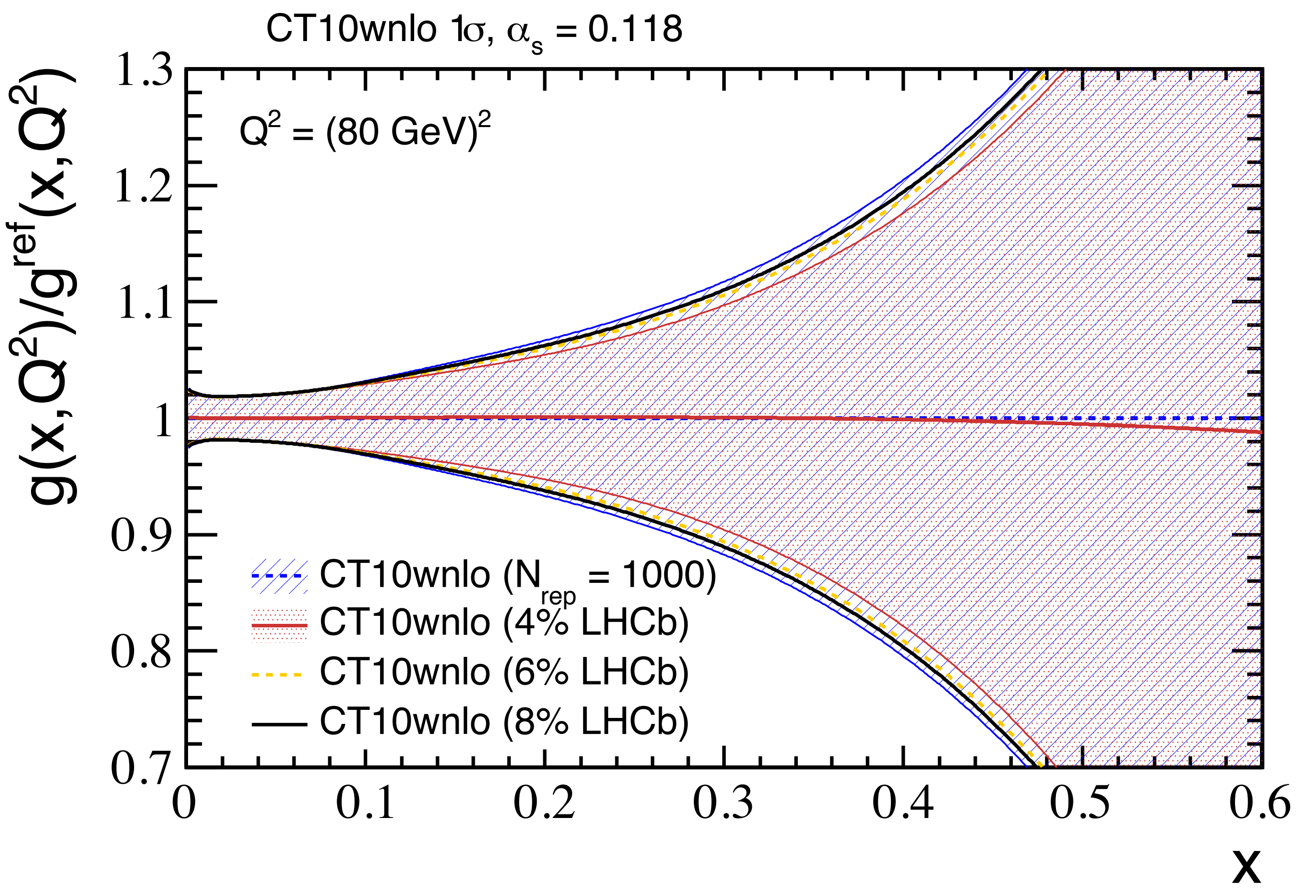
2) Generate 1000 Replicas and compare, $g^{\mathrm{rep}}(x, [Q = 80 \text{ GeV}]^2)$

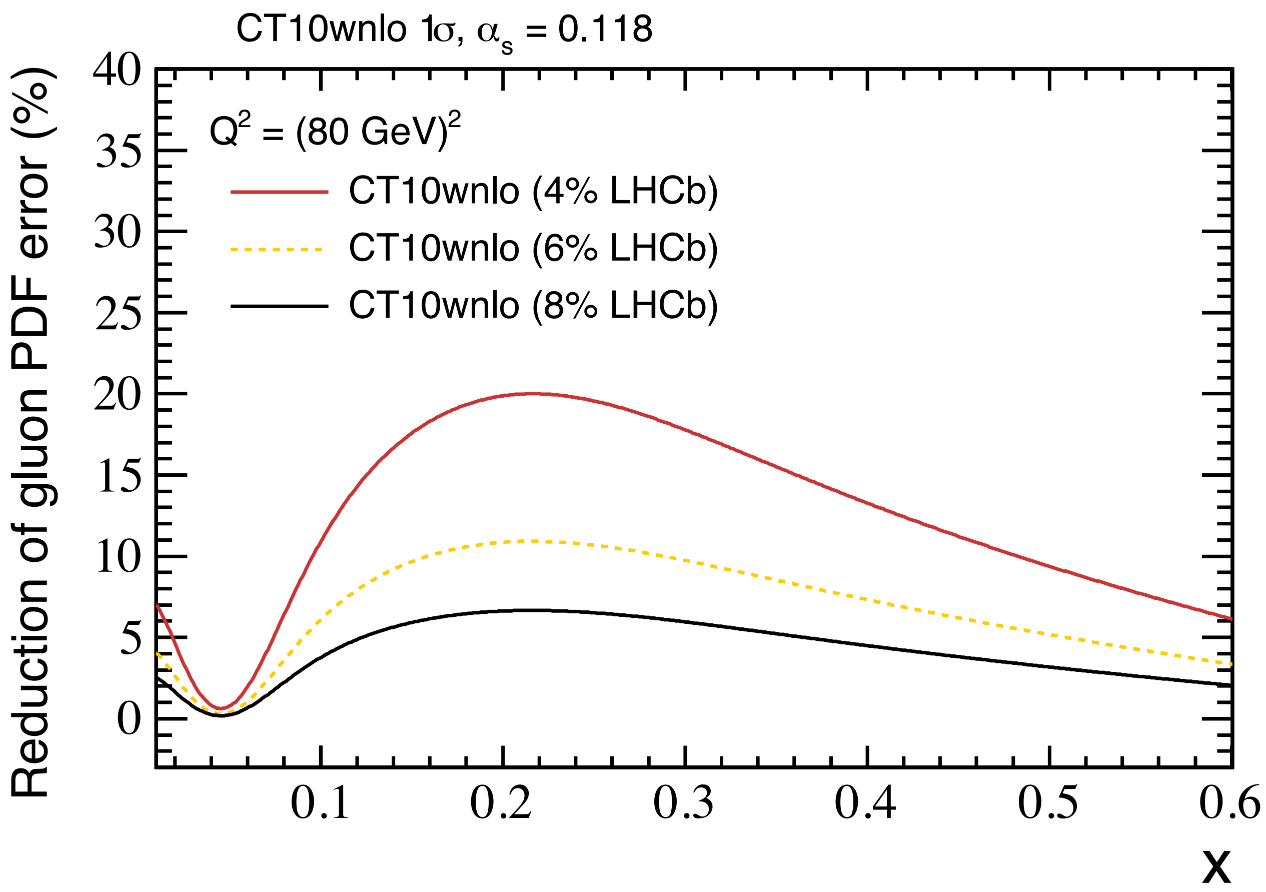


Follow the recipe - steps 3, 4

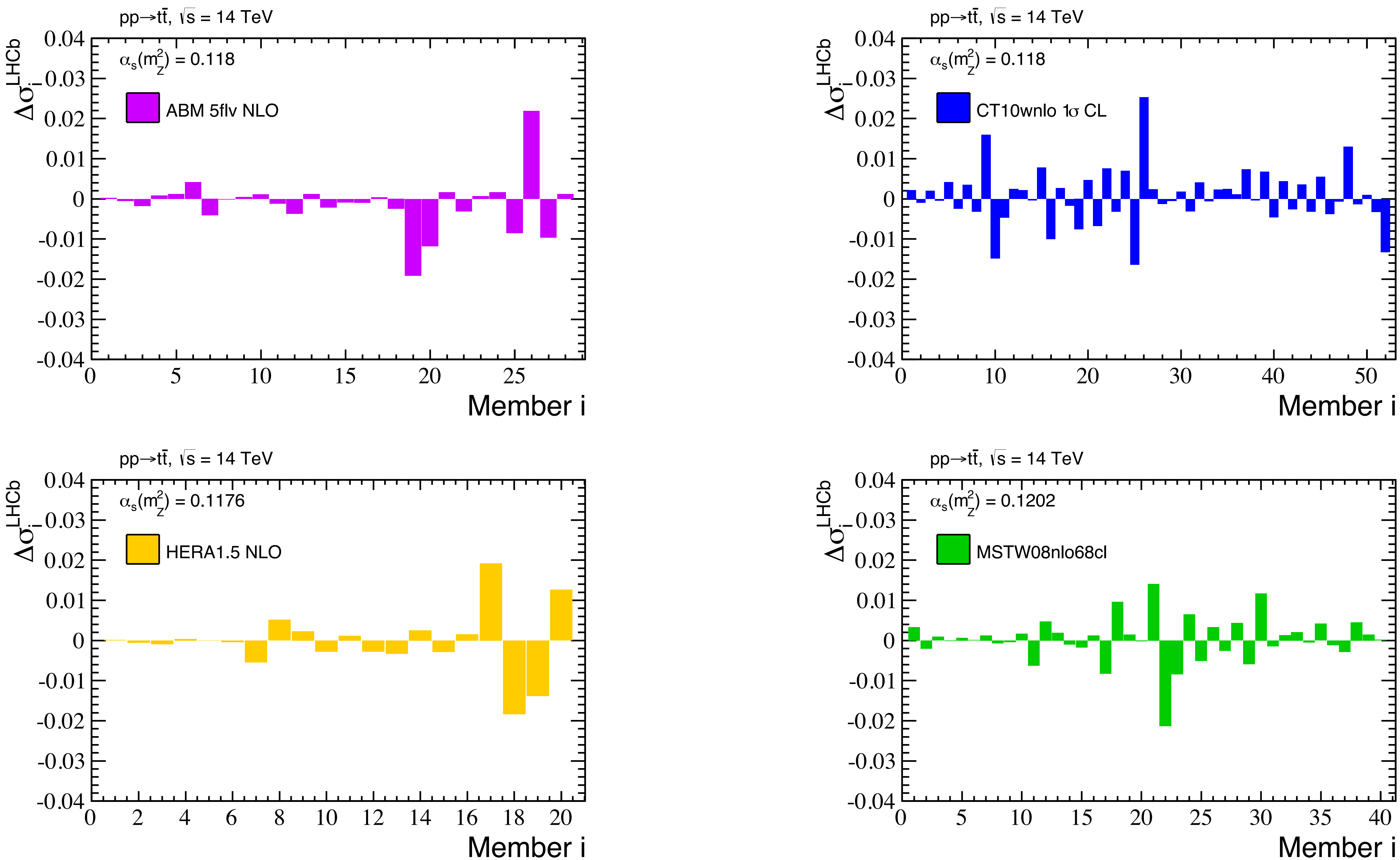
3) Pick some pseudo LHCb cross-section data, $\bar{X}_0 = \frac{1}{N_{\text{rep}}} \sum_{k=1}^{N_{\text{rep}}} X_0(\mathcal{S}_0)[1 + R_{k0}]$

4) Apply weights found using pseudodata to reweight evolved gluon PDF



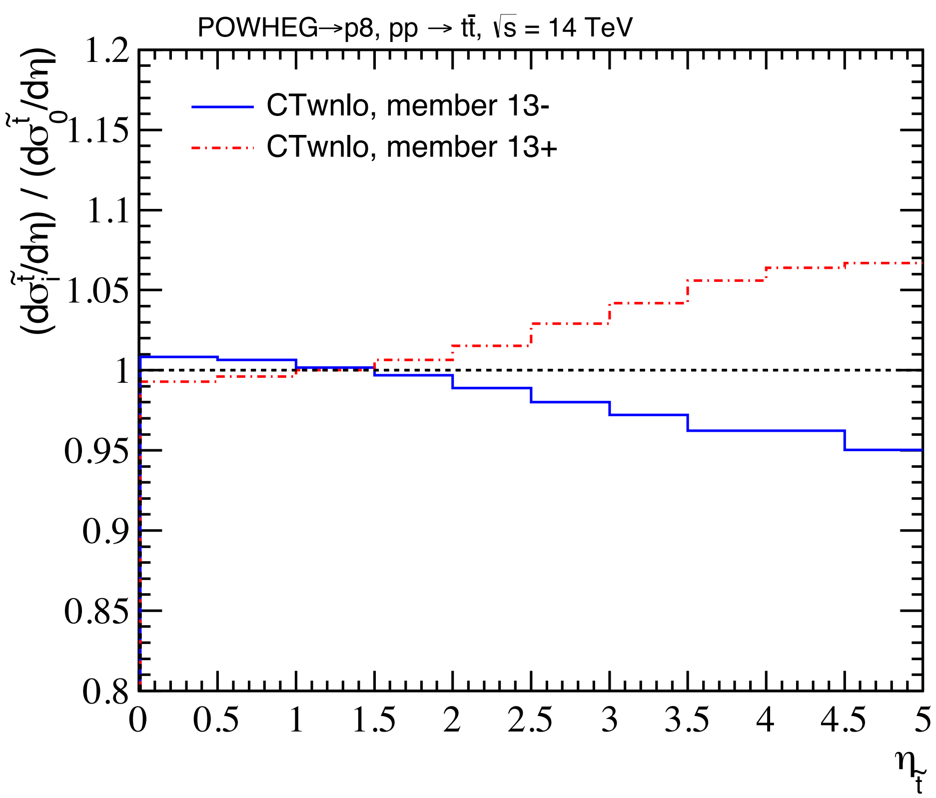


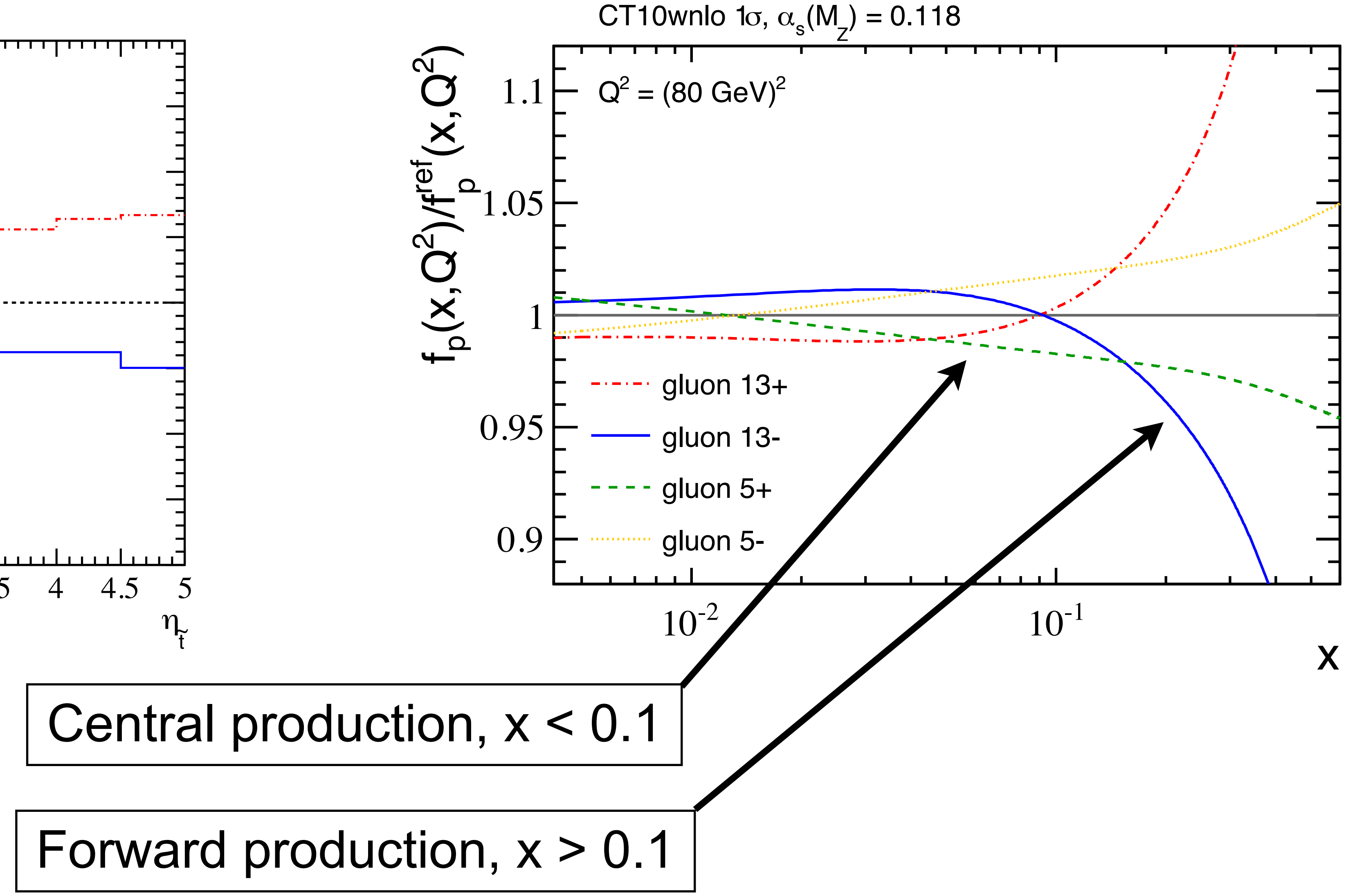
Summary of eigenvector sensitivity



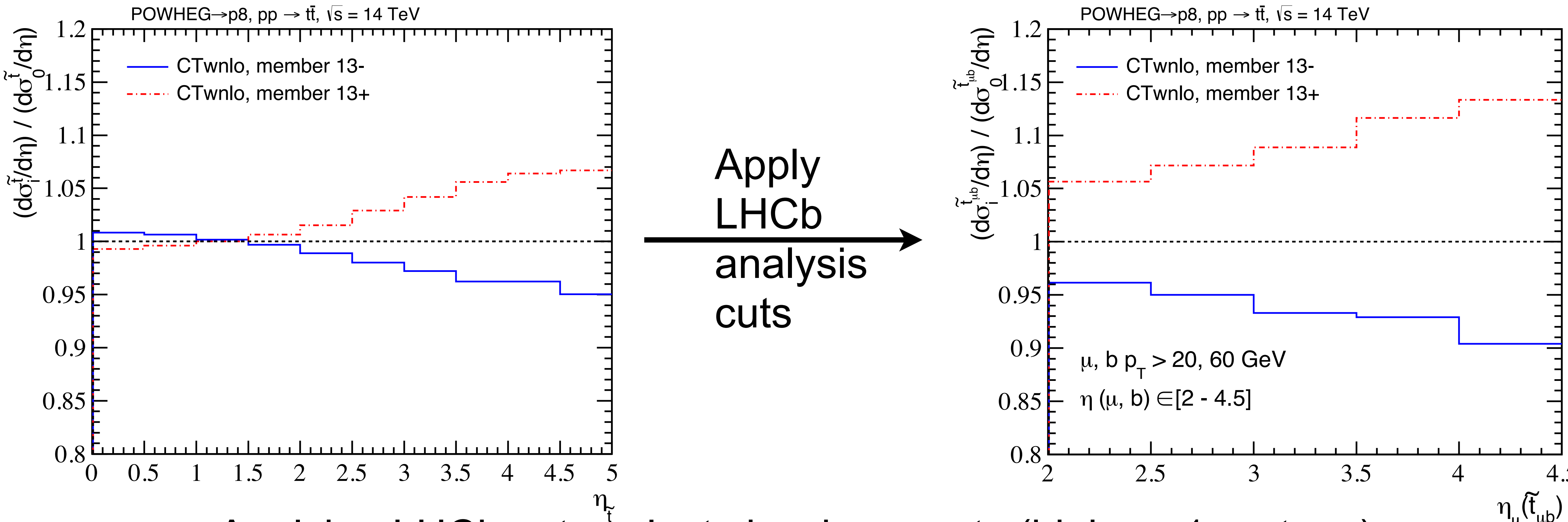
$$\Delta X_j^{\pm} = \frac{X(\mathcal{S}_j^{\pm}) - X(\mathcal{S}_0)}{X(\mathcal{S}_0)}$$

Effect of LHCb analysis cuts



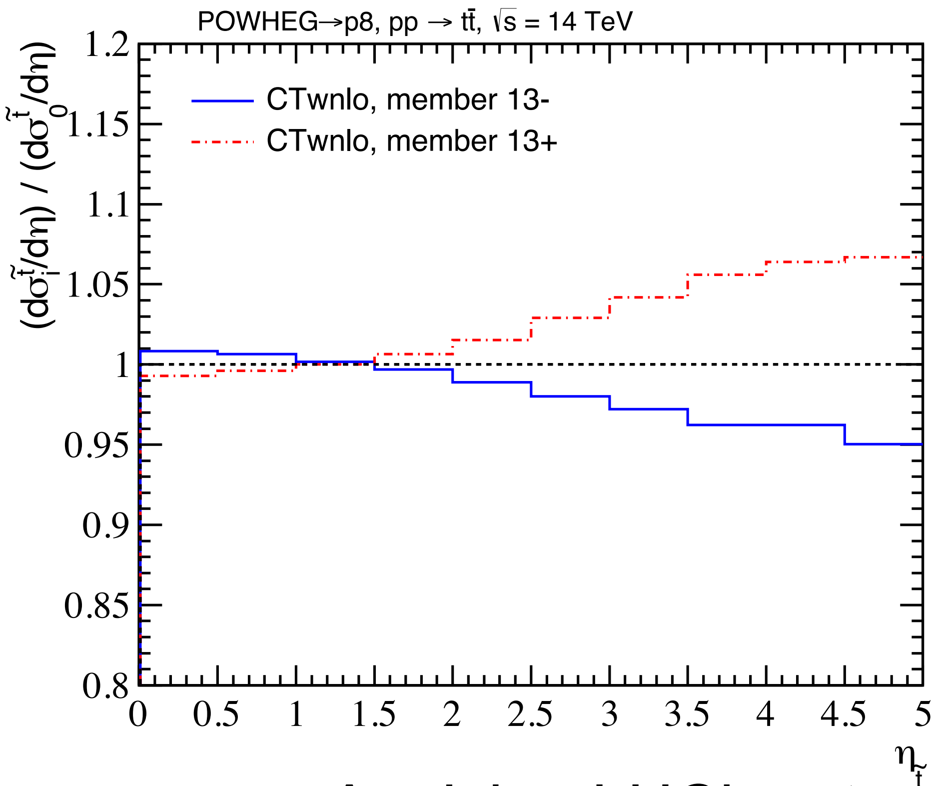


Effect of LHCb analysis cuts

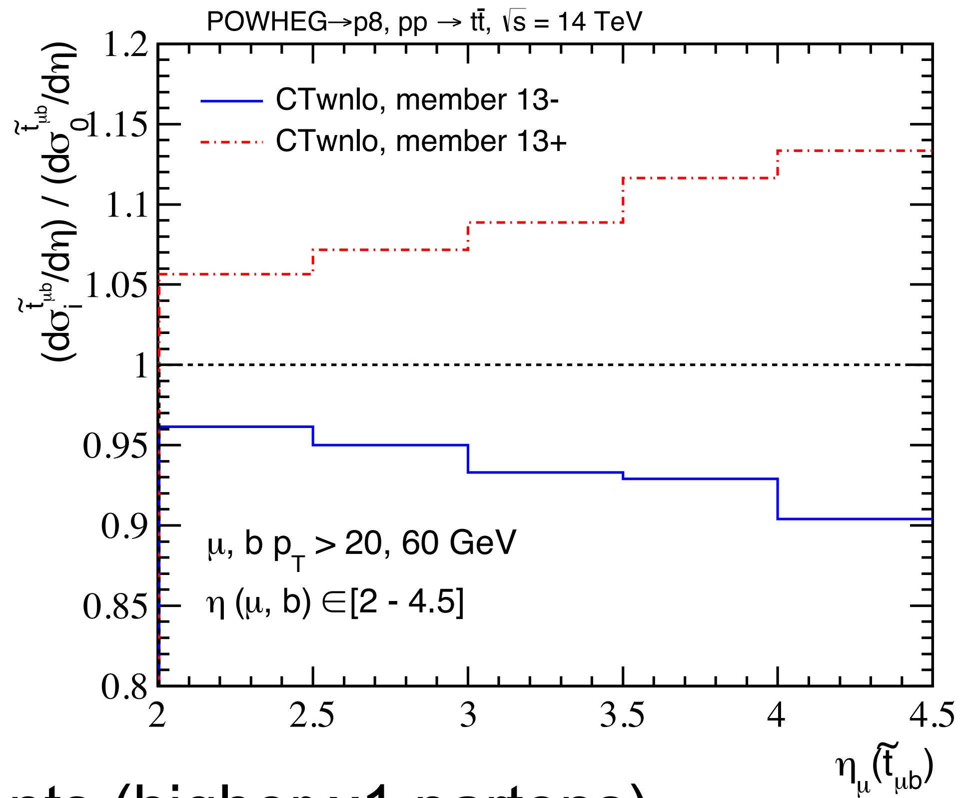


Applying LHCb cuts selects harder events (higher x1 partons)

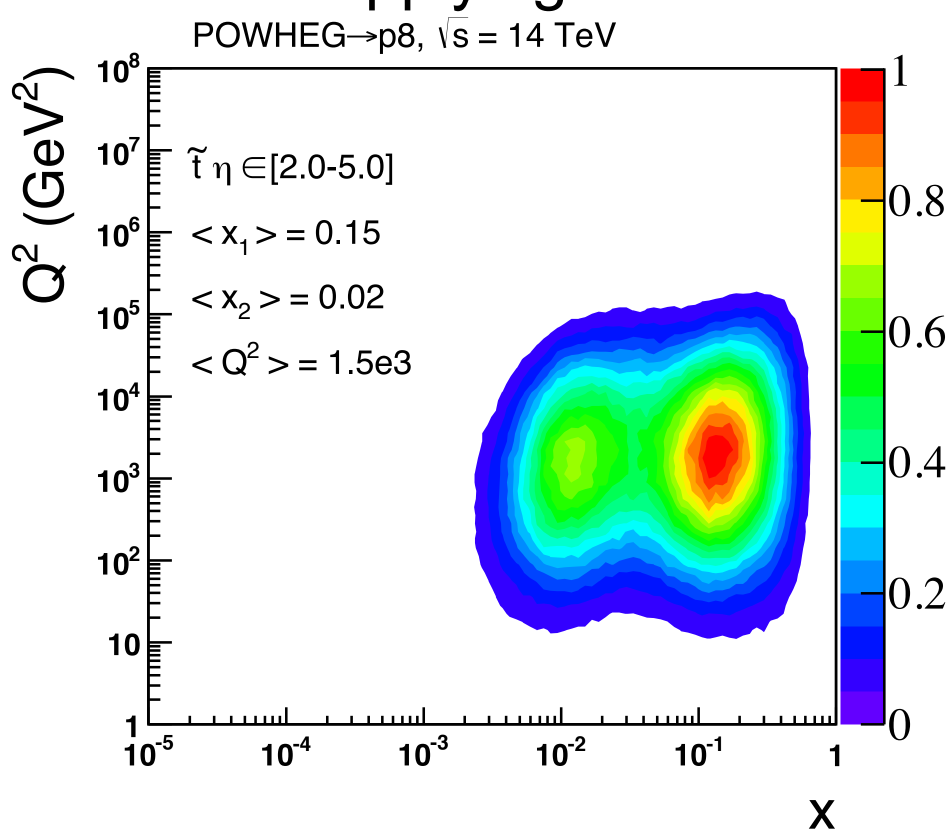
A few more comments



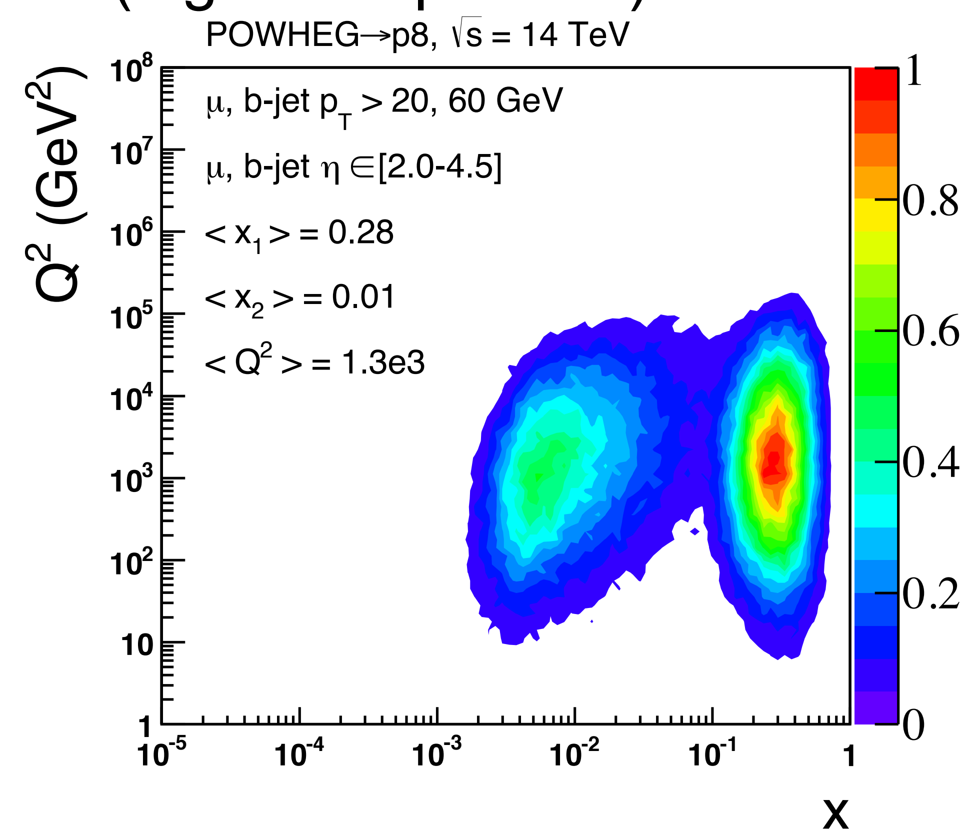
Apply LHCb analysis cuts →



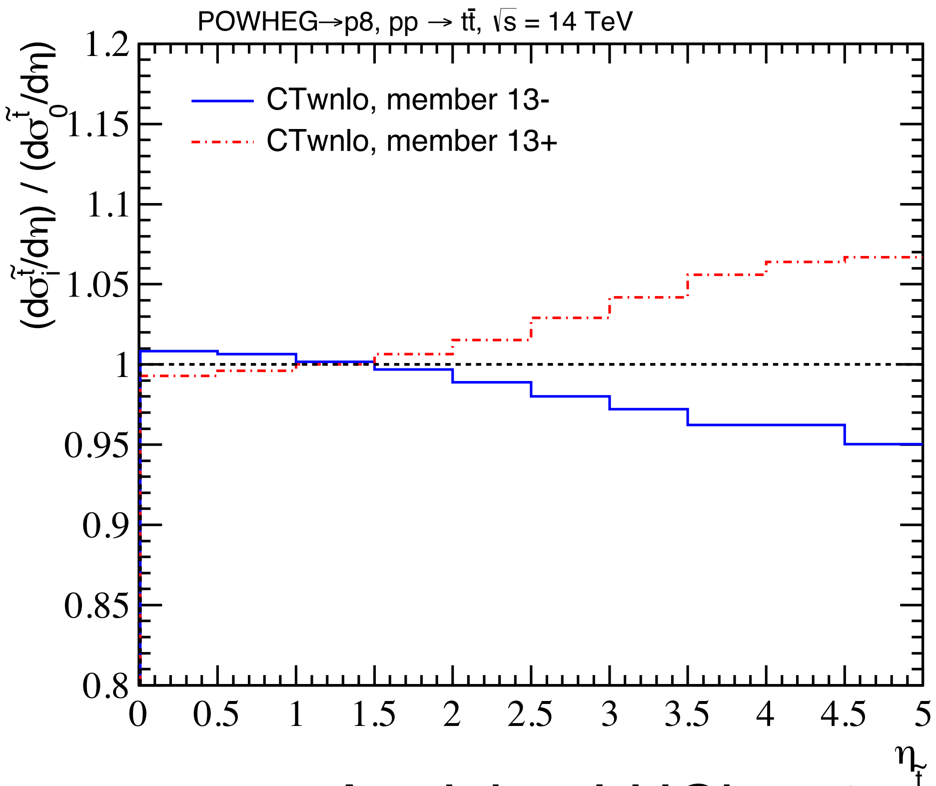
Applying LHCb cuts selects harder events (higher x1 partons)



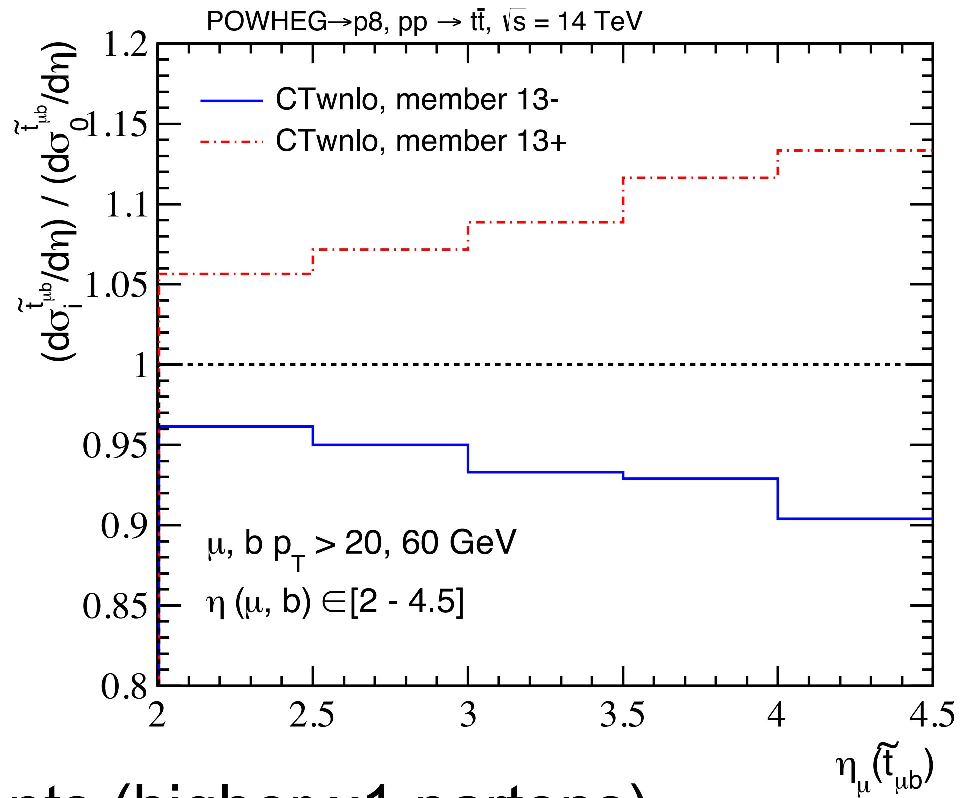
Apply LHCb analysis cuts →



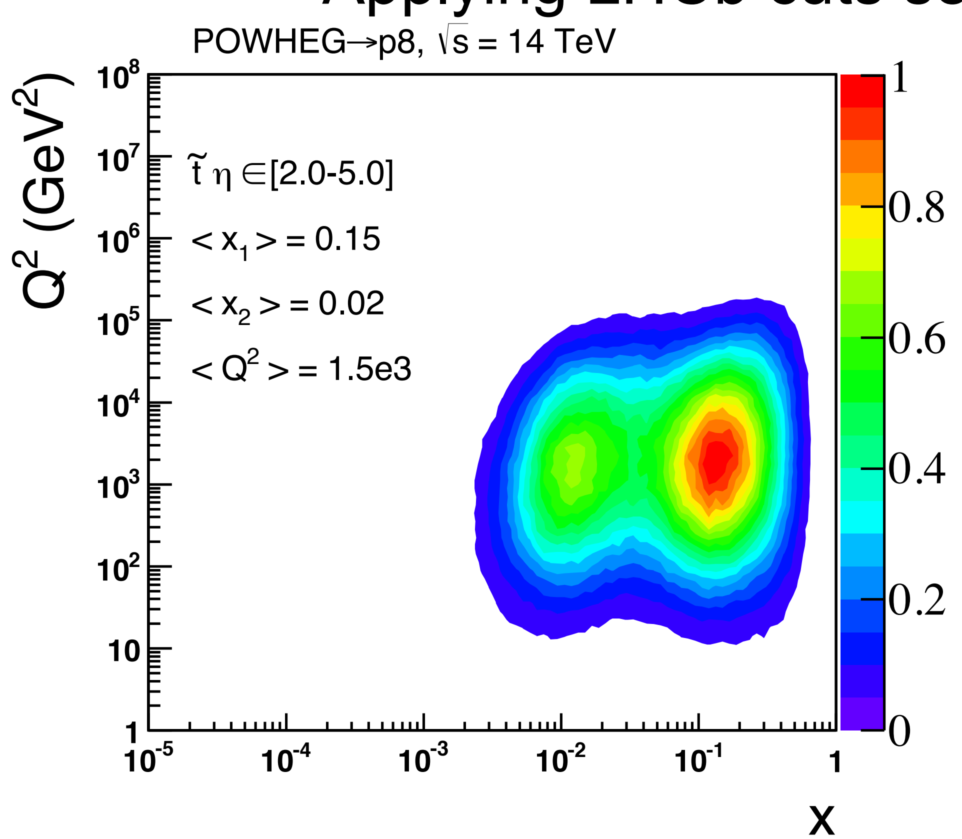
A few more comments



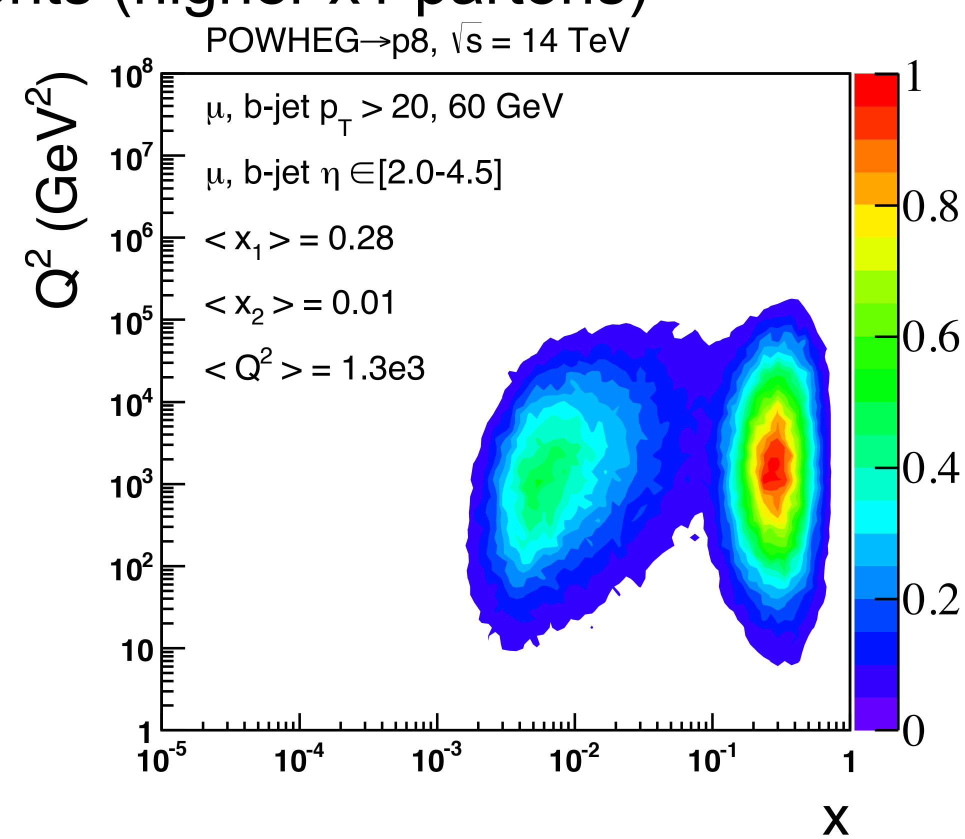
Apply LHCb analysis cuts



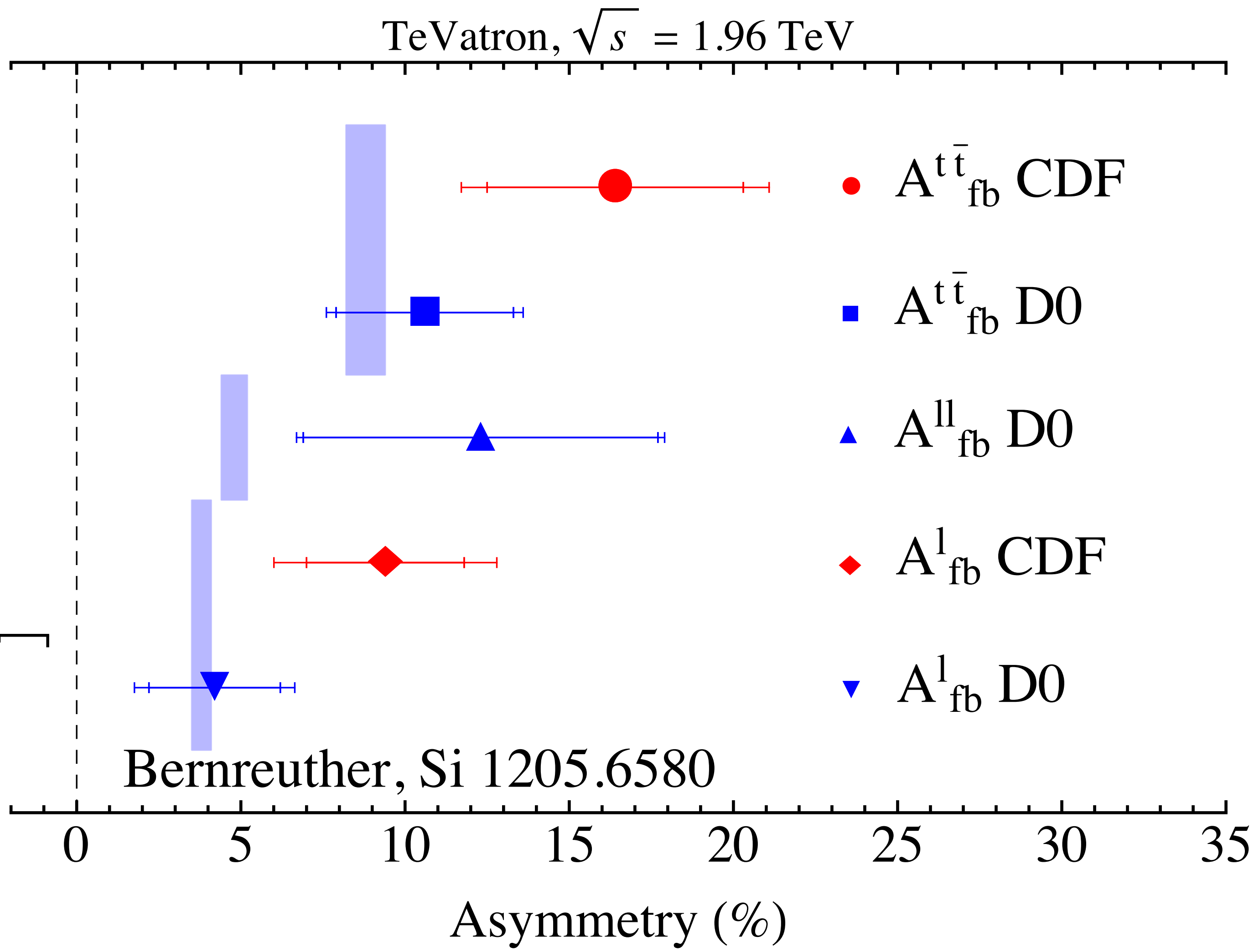
Applying LHCb cuts selects harder events (higher x1 partons)

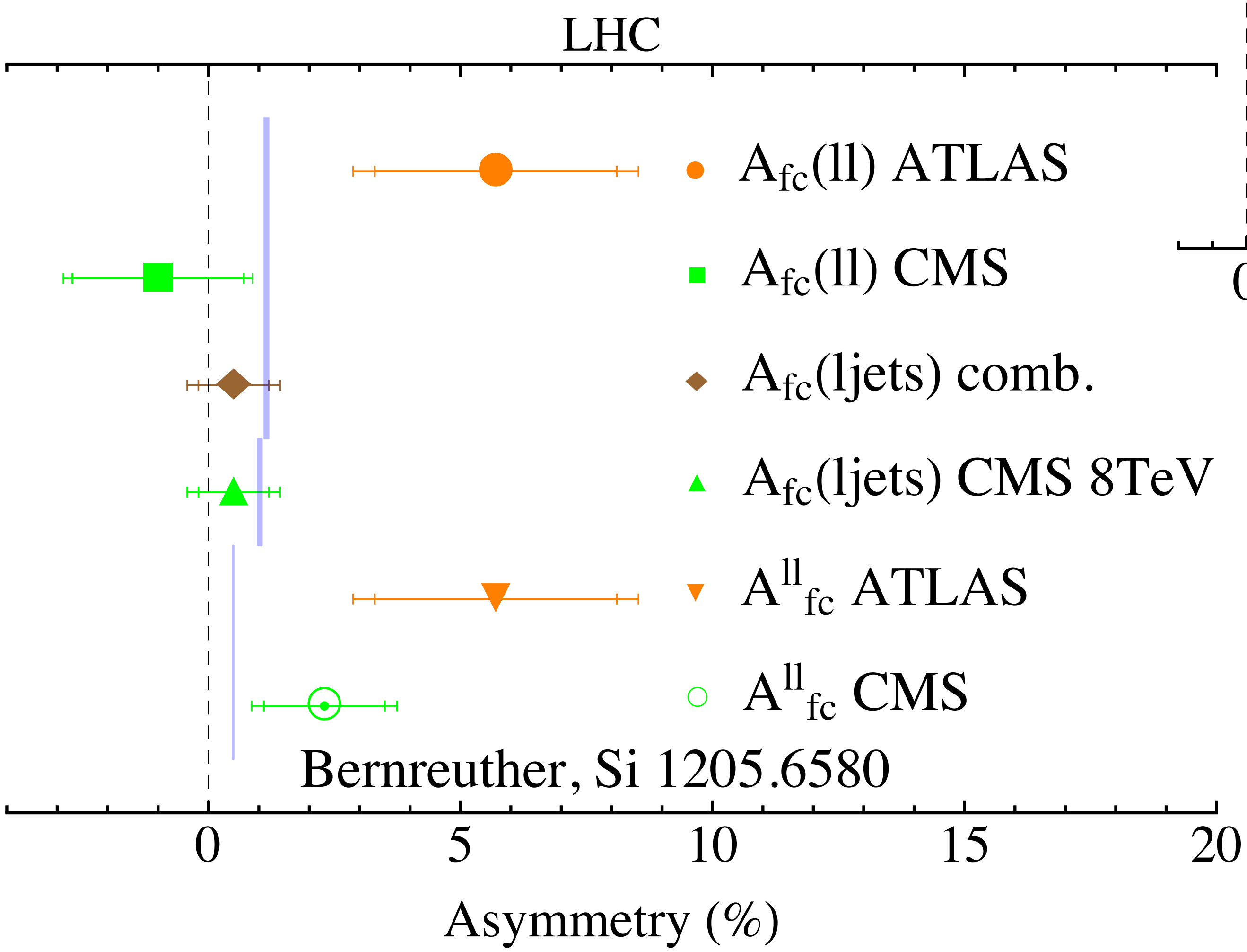


Apply LHCb analysis cuts



Asymmetry summaries





LHC 8TeV Asym Systematics

CMS-PAS-TOP 12 033
8TeV

Systematic uncertainty	shift in inclusive A_C	range of shifts in differential A_C
JES	0.001	0.001 – 0.005
JER	0.001	0.001 – 0.005
Pileup	0.001	0.000 – 0.003
b tagging	0.000	0.001 – 0.003
Lepton ID/sel. efficiency	0.002	0.001 – 0.003
Generator	0.003	0.001 – 0.015
Hadronization	0.000	0.000 – 0.016
p_T weighting	0.001	0.000 – 0.003
Q^2 scale	0.003	0.000 – 0.009
W+jets	0.002	0.001 – 0.007
Multijet	0.001	0.002 – 0.009
PDF	0.001	0.001 – 0.003
Unfolding	0.002	0.001 – 0.004
Total	0.006	0.007 – 0.022